

# NAVAL POSTGRADUATE SCHOOL

## Monterey, California



## THESIS

### OPTIMALLY SCHEDULING EA-6B DEPOT MAINTENANCE

by

Bradley P. Meeks

September 1999

Thesis Advisor:  
Second Reader:

Robert F. Dell  
Alan R. Washburn

Approved for public release; distribution is unlimited.

DTIC QUALITY INSPECTED 4

19991027 126

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE  
September 1999

3. REPORT TYPE AND DATES COVERED  
Master's Thesis

4. TITLE AND SUBTITLE  
OPTIMALLY SCHEDULING EA-6B DEPOT MAINTENANCE

5. FUNDING NUMBERS

6. AUTHOR(S)  
Meeks, Bradley P.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  
Naval Postgraduate School  
Monterey, CA 93943-5000

8. PERFORMING  
ORGANIZATION REPORT  
NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING /  
MONITORING  
AGENCY REPORT NUMBER

## 11. SUPPLEMENTARY NOTES

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

## 12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

## 12b. DISTRIBUTION CODE

## 13. ABSTRACT (maximum 200 words)

Ranging from Operation Desert Storm to combat actions in the Balkans, EA-6B Prowler aircraft lie at the heart of nearly all tactical aircraft strikes. Providing a fleet capable of such combat actions in the next decade challenges the Prowler community to efficiently schedule EA-6B depot maintenance services. By 2009, EA-6B depots must conduct 80 wing center section replacements, 144 major aircraft modifications and standard depot level maintenance 154 times. There are several complex rules governing when each Prowler is eligible for each service; these rules are also flexible enough to allow more induction schedules than can be evaluated manually in a reasonable amount of time. Since each service removes aircraft from mission inventory for six to 12 months and performing multiple services together requires less time than performing services independently, services should be combined whenever possible. This thesis develops a mixed integer linear program, EA-6B Depot Maintenance Optimization Model (EDMOM), to help schedule EA-6B aircraft for depot maintenance services. EDMOM minimizes total time aircraft are removed from mission inventory; it produces an induction schedule for the EA-6B fleet through 2009 that adheres to all appropriate rules and conducts 378 services in only 216 inductions, requiring 2,446 total months. Without combining services, it would require 3,630 months, nearly a 50 percent increase.

## 14. SUBJECT TERMS

Mixed Integer Linear Programming, Aircraft Depot Maintenance, Optimization,

15. NUMBER OF  
PAGES  
85

16. PRICE CODE

17. SECURITY CLASSIFICATION OF  
REPORT  
Unclassified

18. SECURITY CLASSIFICATION OF  
THIS PAGE  
Unclassified

19. SECURITY CLASSIFI- CATION  
OF ABSTRACT  
Unclassified

20. LIMITATION  
OF ABSTRACT  
UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)  
Prescribed by ANSI Std. Z39-18

THIS PAGE INTENTIONALLY LEFT BLANK.

Approved for public release; distribution is unlimited

**OPTIMALLY SCHEDULING EA-6B DEPOT MAINTENANCE**

Bradley P. Meeks  
Lieutenant Commander, United States Navy  
B.S., Saint John's University, 1987

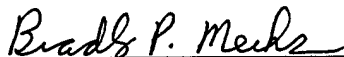
Submitted in partial fulfillment of the  
requirements for the degree of

**MASTER OF SCIENCE IN OPERATIONS RESEARCH**

from the

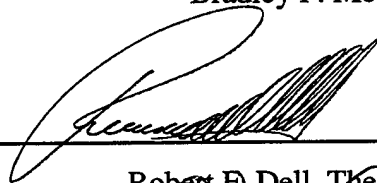
**NAVAL POSTGRADUATE SCHOOL  
September 1999**

Author:

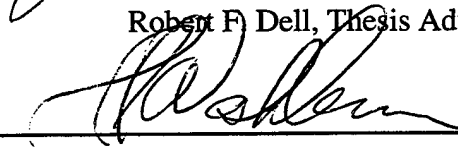


Bradley P. Meeks

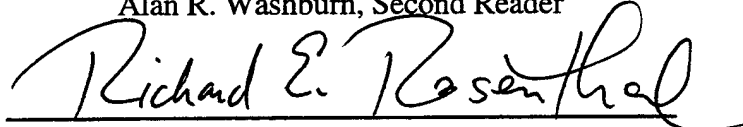
Approved by:



Robert F. Dell, Thesis Advisor



Alan R. Washburn, Second Reader



Richard E. Rosenthal, Chairman  
Department of Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK.

## ABSTRACT

Ranging from Operation Desert Storm to combat actions in the Balkans, EA-6B Prowler aircraft lie at the heart of nearly all tactical aircraft strikes. Providing a fleet capable of such combat actions in the next decade challenges the Prowler community to efficiently schedule EA-6B depot maintenance services. By 2009, EA-6B depots must conduct 80 wing center section replacements, 144 major aircraft modifications and standard depot level maintenance 154 times. There are several complex rules governing when each Prowler is eligible for each service; these rules are also flexible enough to allow more induction schedules than can be evaluated manually in a reasonable amount of time. Since each service removes aircraft from mission inventory for six to 12 months and performing multiple services together requires less time than performing services independently, services should be combined whenever possible. This thesis develops a mixed integer linear program, EA-6B Depot Maintenance Optimization Model (EDMOM), to help schedule EA-6B aircraft for depot maintenance services. EDMOM minimizes total time aircraft are removed from mission inventory; it produces an induction schedule for the EA-6B fleet through 2009 that adheres to all appropriate rules and conducts 378 services in only 216 inductions, requiring 2,446 total months. Without combining services, it would require 3,630 months, nearly a 50 percent increase.

## **DISCLAIMER**

The reader is cautioned that the computer program developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the program is free of computational and logic errors, they cannot be considered validated. Any application of this program without verification is at the risk of the user.

## TABLE OF CONTENTS

I.	INTRODUCTION.....	1
	A. EA-6B PAA INVENTORY SHORTAGES.....	1
	B. PLANNED EVENTS THAT REDUCE AIRCRAFT INVENTORY .....	3
	1. WCS Replacements .....	3
	2. SDLM .....	5
	3. Major Aircraft Modifications.....	7
	C. PROBLEM STATEMENT.....	8
	D. THESIS OUTLINE.....	9
II.	RELATED RESEARCH .....	11
III.	MODEL DEVELOPMENT .....	15
	A. ASSUMPTIONS AND REQUIREMENTS .....	15
	B. MODEL FORMULATION .....	20
	C. SET DERIVATIONS .....	25
	1. Additional Sets and Data.....	25
	2. Derivation of AvailSet <sub>a,o</sub> .....	29
	3. Derivation of SDLM2SET <sub>a,o,o',p</sub> .....	30
IV.	IMPLEMENTATION AND COMPUTATIONAL RESULTS.....	33
	A. EA-6B FLEET AND SERVICE COMPONENT AVAILABILITY.....	33
	B. IMPLEMENTATION OF EDMOM.....	35
	C. MODEL FLEXIBILITY .....	38



IV. CONCLUSION AND RECOMMENDATIONS .....	41
A. CONCLUSION.....	41
B. RECOMMENDATIONS.....	41
APPENDIX A. LIST OF ABBREVIATIONS AND ACRONYMS.....	43
APPENDIX B. EDMOM'S RECOMMENDED INDUCTION SCHEDULE.....	45
APPENDIX C. MODEL FLEXIBILITY INDUCTION SCHEDULE.....	57
LIST OF REFERENCES .....	69
INITIAL DISTRIBUTION LIST.....	71

## EXECUTIVE SUMMARY

The variety and pace of United States combat actions over the past decade have been at an unprecedented high. Ranging from Operation Desert Storm to combat actions in the Balkans, EA-6B Prowler aircraft lie at the heart of nearly all tactical aircraft strikes. Providing a fleet capable of such combat actions in the next decade challenges the Prowler community to efficiently schedule EA-6B depot maintenance services.

EA-6B depot maintenance services are Wing Center Section (WCS) replacements, Standard Depot Level Maintenance (SDLM) and major aircraft modifications. WCS replacements address deteriorating EA-6B wing fatigue life by replacing various wing components. SDLM restores aircraft to a material condition that can be maintained in the fleet. Major aircraft modifications, such as state-of-the-art Improved Capability III, keep the EA-6B on the cutting edge of electronic warfare. By 2009, EA-6B depots must conduct 80 WCS replacements, 154 SDLMs and 144 major aircraft modifications.

There are several complex rules governing when each Prowler is eligible for each service; these rules are also flexible enough to allow more induction schedules than can be evaluated manually in a reasonable amount of time. For example, SDLMs must be scheduled within a nine-month availability window. Additionally, a "Level Loading" policy attempts to evenly distribute and reduce the number of SDLMs per fiscal year. Since each service removes aircraft from mission inventory for six to 12 months and performing multiple services together requires less time than performing services independently, services should be combined whenever possible.

This thesis develops a mixed integer linear program, EA-6B Depot Maintenance Optimization Model (EDMOM), to help schedule EA-6B aircraft for depot maintenance services. EDMOM minimizes total time aircraft are removed from mission inventory. It produces an induction schedule for the EA-6B fleet through 2009 that adheres to all appropriate rules and conducts 378 services in only 216 inductions, requiring 2,446 total months. Without combining services, it would require 3,630 months, nearly a 50 percent increase. EDMOM additionally reduces the maximum yearly-predicted SDLMs by ten.

An often-overlooked byproduct of combat operations is an increased operational use of aircraft. By a simple modification of data, EDMOM is able to show the effects of doubling the projected EA-6B utilization rate for a six-month period. In this scenario, EDMOM conducts the same 378 services in a mere 214 inductions, requiring 2,411 total months; with only a slight variation in the number of inductions recommended per fiscal year.

In an era of decreasing budgets and increasing operational commitments, all attempts to optimally manage scarce resources must be made. This thesis develops an optimization model to assist the EA-6B community manage one of its scarcest resources, aircraft on the cutting edge of electronic warfare technology.

## ACKNOWLEDGEMENT

I would like to thank PMA-234, in particular CDR Tom Payne, for providing financial and technical support. Without it, this thesis would not have been possible.

I thank Gary Ellis of SEMCOR for his willingness to provide much needed technical support. His in-depth knowledge and continual flow of information significantly impacted every stage in the development of this thesis.

Special thanks goes to Dr. Rob Dell for his dedication of time, keen insight, continual patience and genuine interest. He truly made this experience enjoyable.

Most importantly, I thank my wife Cheryl for her never-ending stream of love, support, understanding and smiles. This thesis is dedicated to her.

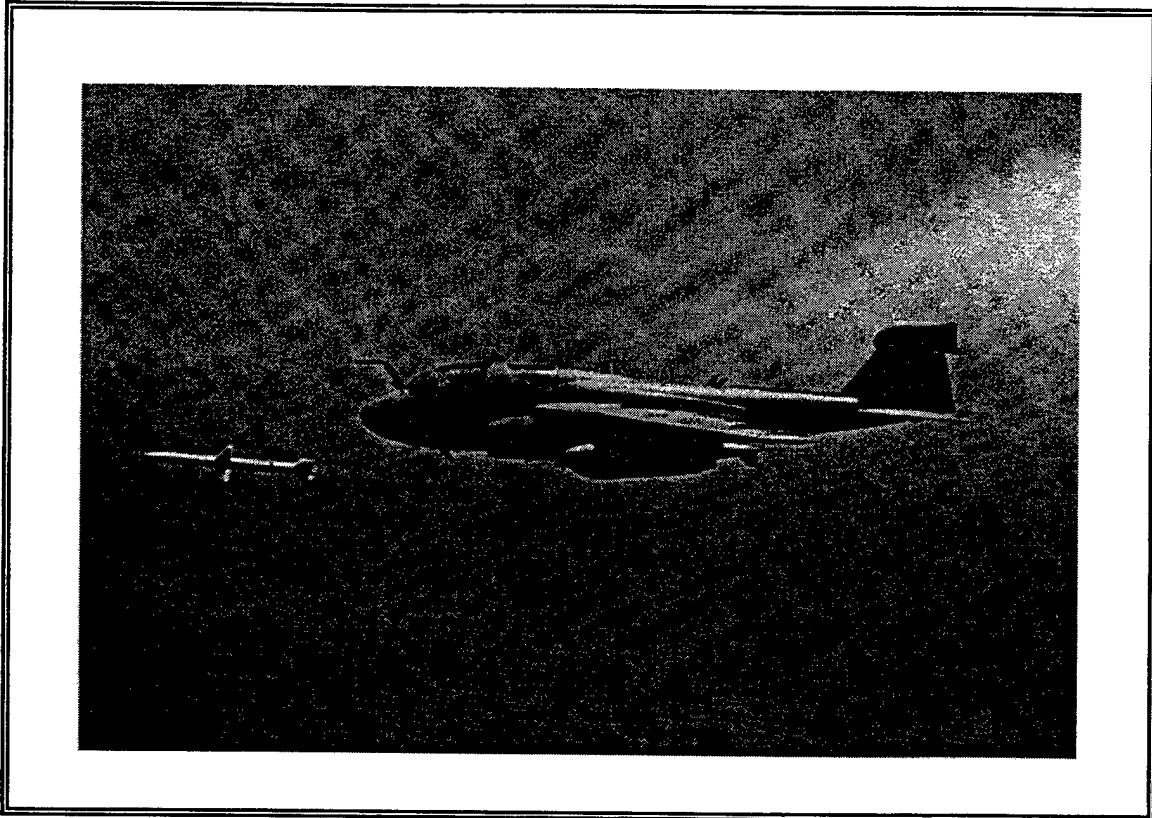
THIS PAGE INTENTIONALLY LEFT BLANK.

## **I. INTRODUCTION**

The Department of the Navy (DON) is authorized a yearly inventory of 104 EA-6B Prowler aircraft (see Figure 1) through fiscal year 2015 (FY-15) [Naval Air Systems Command (NAVAIR), 1997]. This inventory, called the Primary Aircraft Authorization (PAA), represents the number of United States Navy (USN) and United States Marine Corps (USMC) mission aircraft authorized. Wing Center Section (WCS) replacement and Standard Depot Level Maintenance (SDLM) services help extend EA-6B service life, but remove aircraft from PAA inventory for 10 to 12 months. Major aircraft modification services keep the EA-6B on the cutting edge of electronic warfare, but also remove them from the PAA inventory. This thesis provides a mixed integer linear program, EA-6B Depot Maintenance Optimization Model (EDMOM), to help schedule EA-6B aircraft for WCS replacement, SDLM and major aircraft modification services while minimizing the time aircraft are removed from PAA inventory.

### **A. EA-6B PAA INVENTORY SHORTAGES**

EA-6B PAA inventory shortages began in 1996 when the DON received tasking to support nearly all Department of Defense tactical electronic warfare missions with the EA-6B. This tasking increased the EA-6B PAA inventory from 80 to 104 starting in FY-98 [NAVAIR, 1997]. Meeting this increase continues to challenge the EA-6B community.



**Figure 1.** An EA-6B fires a High Speed Anti-Radiation Missile (HARM) [Electronic Attack Squadron One Twenty Eight, 1999]. Ranging from Operation Desert Shield/Storm to combat actions in the Balkans, EA-6B aircraft lie at the heart of nearly all tactical aircraft strikes.

In October 1998, the 14<sup>th</sup> EA-6B Operational Advisory Group (OAG) and Executive Steering Committee (ESC) identified the most significant near-term challenge facing the EA-6B community as a shortage in PAA inventory [Commander, Electronic Combat Wing, U.S. Pacific Fleet (COMVAQWINGPAC), 1998]. In an attempt to reduce this shortage, the OAG recommends, when feasible, combining depot maintenance services; these combined services require less time than separate inductions. Currently, depot maintenance services involve WCS replacements, SDLM and major aircraft modifications.

Under the direction of Program Executive Officer, Tactical Aircraft Programs, the Program Manager for the EA-6B (PMA-234) acquires and manages all EA-6B aircraft and associated weapon systems [NAVAIR, 1998a]. PMA-234 performs the difficult task of scheduling the induction of EA-6Bs for depot maintenance services manually: the schedule of inductions is called the Master Plan.

## **B. PLANNED EVENTS THAT REDUCE AIRCRAFT INVENTORY**

Three planned events reduce the EA-6B PAA inventory: WCS replacement, SDLM and major aircraft modification services.

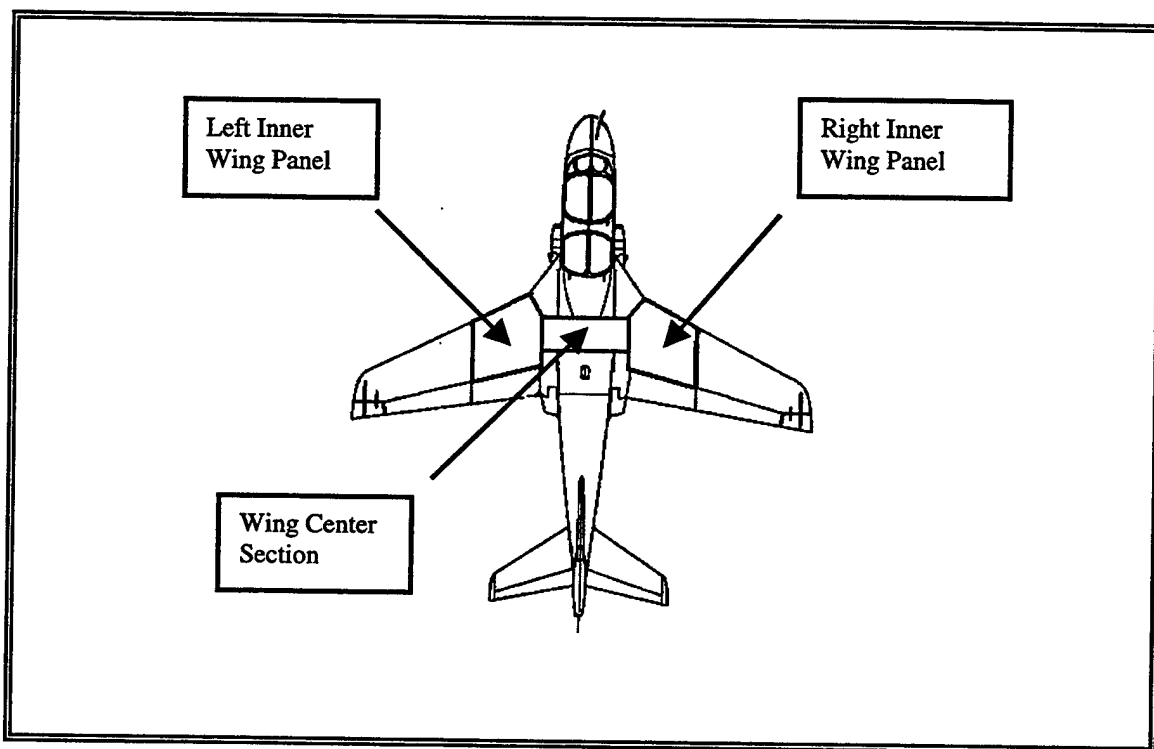
### **1. WCS Replacements**

The first 65 production and replacement EA-6B wings contained sections constructed of Type 7079 aluminum (T-7079). Inspections conducted early in the life of these 65 wings discovered T-7079 to be extremely strong and fatigue resistant, but highly susceptible to stress corrosion. T-7079 also exhibited highly unpredictable stress corrosion crack formation and growth rates. Due to these alarming discoveries and a fear of possible catastrophic wing failure, subsequent production and replacement EA-6B wings contained sections constructed of Type 7050 aluminum (T-7050), a superior grade. Regardless of the type of aluminum used, engineering studies reveal the most critical factor defining EA-6B service life is the aircraft wing, specifically the WCS.

A WCS replacement program began in 1991 to address the deteriorating wing fatigue life of EA-6B aircraft. Wing fatigue life is the projected usefulness of the wing as a function of gravitational acceleration forces (G) applied to the aircraft; quantified by the



term Fatigue Life Expenditure (FLE). FLE is a strongly increasing function of Gs applied to the aircraft. For example, a single seven-G hit on a T-7050 wing is equivalent to 14 one-G hits. Once an aircraft expends 100 percent FLE, this program calls for a replacement of the Left Inner Wing Panel, Right Inner Wing Panel and the WCS itself with components constructed of T-7050 (see Figure 2). PMA-234 schedules aircraft for the WCS replacement program upon expending 95 percent FLE.



**Figure 2.** Top view of an EA-6B aircraft depicting the Left Inner Wing Panel, Right Inner Wing Panel and Wing Center Section (WCS). This thesis provides a mixed integer linear program, EA-6B Depot Maintenance Optimization Model (EDMOM), to help schedule EA-6B aircraft for WCS replacements, SDLMs and major aircraft modifications.

In a further attempt to extend the EA-6B service life, COMVAQWINGPAC implemented the EA-6B Fatigue Life Expenditure Management Program in June 1997 [COMVAQWINGPAC, 1997]. This program coordinates the expenditure of wing fatigue

life with planned WCS replacements and applies to all COMVAQWINGPAC EA-6B aircraft, but not USMC aircraft.

The heart of the FLE Management Program is an aircraft by aircraft assessment designed to use all remaining wing fatigue life prior to WCS replacement. At the start of this program, all aircraft received classification based on percentage of wing fatigue life expended. High-FLE aircraft received an administrative restriction of three-Gs in an attempt to prevent expending 100 percent FLE prior to WCS replacement. Medium-FLE aircraft received a yearly four-G equivalence hit budget such that FLE would not exceed 95 percent by FY-05. Low-FLE aircraft received a yearly four-G equivalence hit budget with a 95 percent FLE target of FY-15.

The Counting Accelerometer Group (CAG) is an aircraft component that records the number of times an aircraft experiences four, five, six and seven-Gs during a flight. Data collected by the CAG is used to manage each low-FLE and medium-FLE aircraft's yearly four-G equivalence hit budget. When this budget reaches zero, the aircraft receives an administrative restriction of three-Gs for the remainder of the year.

## **2. SDLM**

SDLM restores an aircraft to a material condition that can be properly maintained at the organizational or intermediate level [NAVAIR, 1998b]. It begins with a comprehensive inspection of selected aircraft components and proceeds by repairing faulty components, performing preventative maintenance and conducting required modifications. Additionally, SDLM ensures compliance with technical directives and replaces components that will require replacement prior to the next anticipated SDLM.

The EA-6B falls under the Aircraft Service Period Adjustment (ASPA) program which evaluates "... the material condition of fleet aircraft, and use(s) this information to more efficiently plan depot maintenance programs" [Office of the Chief of Naval Operations (OPNAV), 1998]. The core of the program consists of an evaluation of selected areas that represent overall aircraft condition. Aircraft failing an ASPA evaluation require a SDLM prior to reintroduction into PAA inventory.

When placed in PAA inventory, aircraft receive a Period End Date (PED). This date reflects the minimum number of months between SDLMs that an aircraft can be "... expected to maintain both reliability and operational availability levels" [NAVAIR, 1991]. For the EA-6B, this period varies from 54 months for new aircraft to 36 months for aircraft that have previously completed a SDLM [OPNAV, 1993]. An ASPA evaluation must be conducted in a window ranging from six months prior to three months after PED. A satisfactory ASPA evaluation keeps the aircraft in PAA inventory an additional 12 months before receiving another ASPA evaluation. An unsatisfactory ASPA evaluation requires the aircraft be inducted for SDLM or preservation (removed from PAA inventory) no later than 90 days after PED [OPNAV, 1998]. Data shows 44 of the last 79 EA-6B ASPA evaluation failures occurred on the fifth evaluation [Wood, 1999]. For new aircraft, this occurs after approximately eight and a half years of service. For aircraft that have completed a SDLM, ASPA failure typically occurs seven years after the completion of the most recent SDLM. Projections of failure prior to the fifth ASPA are made based on material condition of the aircraft during its most recent ASPA evaluation. For example, if

an aircraft marginally passes its third ASPA, projections show an anticipated fail on the fourth ASPA. PMA-234 incorporates these projections when scheduling SDLM inductions.

### **3. Major Aircraft Modifications**

In attempts to remain on the cutting edge of safety and electronic warfare, the EA-6B has continually evolved through a series of major aircraft modifications. The first major aircraft modification, Expanded Capability (EXCAP), began in FY-73. EXCAP preceded the introduction of the Improved Capability I (ICAP-I) modification in FY-76. Improved Capability II/Block-82 (Block-82) modifications began in FY-84. Only a select few aircraft received the short-lived Improved Capability II/Block-86 (Block-86) modification. All EXCAP, ICAP-I, Block-82 and Block-86 modifications have been completed. Only two major modifications are currently being performed on the EA-6B: Improved Capability II/Block-89 (Block-89) and Improved Capability II/Block-89A (Block-89A). Prototype Improved Capability III (ICAP-III) modifications will begin in FY-00.

Block-89 modifications began in FY-91. This modification specifically addresses flight safety issues. Block-89 incorporates fire safety upgrades that include a Halon fire extinguishing system and also provides a yaw rate indicating system, additional caution lights and a modified fuel system.

Block-89A modifications began in FY-98. This modification adds a Global Positioning System while converting the Inertial Navigational System for use as the primary attitude reference source. Block-89A supports future growth by providing an upgrade to the AYK-14 computer and adding a dual 1553 data buss. An added ARC-210

V/UHF radio improves inter-service interoperability. Block-89A also provides an aircraft wiring harness replacement.

State-of-the-art ICAP-III modifications primarily focus on radar receiver upgrades allowing expanded frequency and azimuth coverage. ICAP-III includes new cockpit displays, integrated communication countermeasures, provisions for joint platform connectivity and selective reactive jamming capabilities. Additionally, ICAP-III improves reliability, maintainability and life cycle costs. Based on current projections, ICAP-III will be the last major EA-6B modification prior to retirement.

Due to the continuum of major aircraft modifications, the present EA-6B PAA inventory contains a mixture of Block-82, Block-89 and Block-89A aircraft. These different block configured aircraft create maintenance, operational and logistical challenges. Maintenance and operational personnel must be trained in the idiosyncrasies of each block configuration. Logistically, aircraft parts may be incompatible between blocks. To assist in reducing the number of different blocks of aircraft in the fleet, stand-alone Block-89 modifications were discontinued. Instead, all Block-82 aircraft inducted for modification receive a combined Block-89 and Block-89A upgrade.

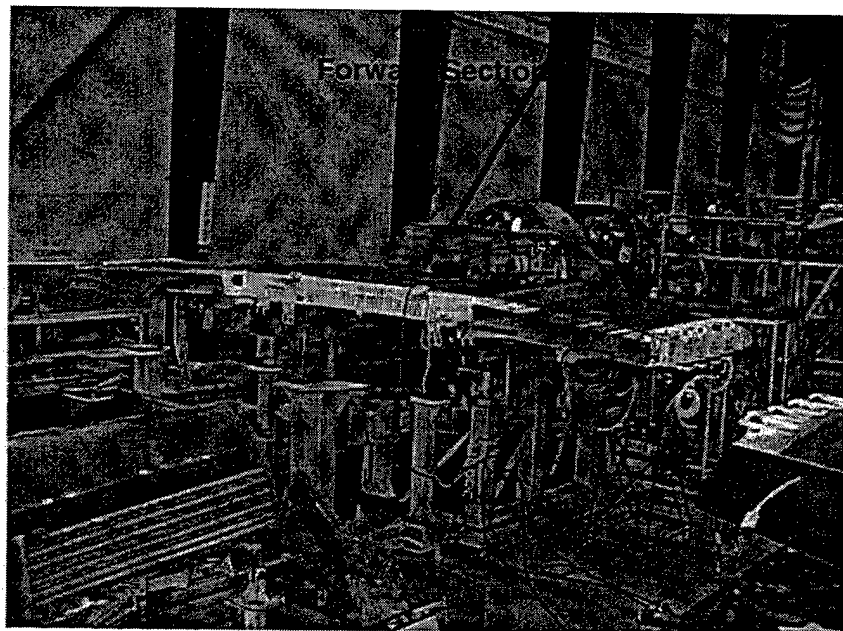
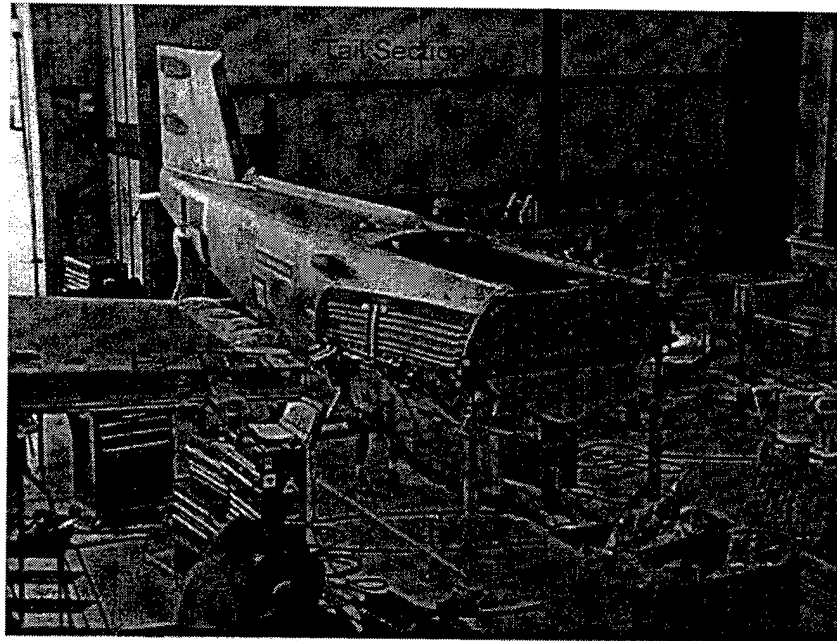
### **C. PROBLEM STATEMENT**

The variety and pace of United States combat actions over the past decade has been at an unprecedented high. Ranging from Operation Desert Storm to combat actions in the Balkans, EA-6B aircraft lie at the heart of nearly all tactical aircraft strikes. Providing an effective EA-6B fleet capable of maintaining this pace into the next decade challenges the

EA-6B community to efficiently schedule depot maintenance services. WCS and SDLM services assist in extending the EA-6B service life to FY-15. To keep the EA-6B on the cutting edge of electronic warfare, while minimizing the amount of time aircraft are removed from PAA inventory, as many major aircraft modification services as possible should be conducted at one time (see Figure 3). This thesis develops a mixed integer linear program, EDMOM, to help PMA-234 meet these challenges. EDMOM schedules EA-6B aircraft for WCS replacements, SDLMs and major aircraft modifications while minimizing the time aircraft are removed from PAA inventory.

#### **D. THESIS OUTLINE**

Chapter II provides an overview of related research. Chapter III describes the development of EDMOM. It contains assumptions and requirements, model formulation and derivations of sets. Chapter IV discusses the computational results of implementing EDMOM. Chapter V presents conclusions and recommendations.



**Figure 3.** The Tail and Forward Sections of an EA-6B during a depot induction [Northrop Grumman, 1999]. To keep the EA-6B on the cutting edge of electronic warfare while minimizing the amount of time aircraft are removed from PAA inventory, as many depot maintenance services as possible should be conducted at one time.

## II. RELATED RESEARCH

Recent operations research literature provides many examples of optimal maintenance scheduling. However, the majority of this literature does not address multiple types of maintenance. The following provides an overview of models that have characteristics similar to that of EDMOM.

Patterson [1997] develops an optimization model to minimize the maintenance time required to prepare the Navy's H-60 Seahawk helicopter fleet for transition to a newly developed maintenance program, the Integrated Maintenance Concept (IMC). Designed to decrease out-of-service time, IMC permits simultaneous performance of organizational, intermediate and depot level maintenance. Transitioning to IMC requires aircraft in a sound structural and material condition. In order to satisfy this requirement, he addresses four major aircraft modifications, various fleet requirements and annual depot induction levels. His model involves two steps. Step one determines monthly allocation of helicopters, by type and squadron, for specific maintenance procedures and operational commitments. This step is formulated as a linear program and requires a rounding heuristic in the event of fractional values. Step two assigns specific aircraft to the monthly allocations determined in step one. To aid the Navy in the transition to IMC, Patterson implements his model with actual H-60 data on a six year planning horizon. This implementation contains approximately 36,000 constraints, 152,000 variables and requires about 31 CPU minutes to solve on an unspecified computer.



Albright [1998] addresses H-60 helicopter maintenance costs by developing a model designed to minimize out-of-service time and maintenance man-hours per 1000 flight-hours (both surrogates for cost) while satisfying required tasking. He defines maintenance tasks and develops two key concepts: task group and task group time. A task group includes maintenance tasks that may be performed at approximately the same time. Task group time defines the time required to perform all tasks in the group. He hypothesizes that task group time is less than the sum of the time required to perform each task in the task group due to the ability to perform some tasks in parallel. Upon identifying task groupings, task group times and windows of opportunity for each task group, Albright solves his set-partitioning-linear-integer program. He exhibits potential reductions in maintenance man-hours per 1000 flight-hours when performing tasks in parallel by implementing his model with 188 tasks. His implementation has approximately 400 constraints and 750 variables. He does not specify solution time.

Jones [1998] explores potential challenges facing the Navy's P-3 Orion community should it adopt a solely calendar based maintenance program, the Isochronal Scheduling Inspection System (ISIS). In contrast to a maintenance program based on both time between inspections and number of flight hours, ISIS adheres to a strict cycle of inspecting, discrepancy correcting and flying based solely on fixed time intervals. Under ISIS, a reduction in maintenance man-hours per flight-hour is expected due to fewer maintenance inductions. He formulates ISIS as a network flow model and simulates the scheduled maintenance and aircraft transfer process. Jones creates a test scenario with 26 aircraft and

three squadrons to exhibit difficulties in implementing ISIS. Fifty percent of his 230 trial runs concluded with scheduling conflicts.

Each of the models described above share some characteristics with EDMOM but none contain all of EDMOM's features.

THIS PAGE INTENTIONALLY LEFT BLANK.

### **III. MODEL DEVELOPMENT**

This chapter describes EDMOM. It contains sections on assumptions and requirements, model formulation and derivations of sets.

#### **A. ASSUMPTIONS AND REQUIREMENTS**

EDMOM uses a generic time division defined as a period. For all computational work presented in this thesis, a period is a month. However, depending on the time horizon of interest and desired resolution of output, a period could easily be extended to represent a quarter or year.

A single type of depot maintenance defines a service. Specifically, a service is any one of the following: SDLM1, SDLM2, WCS, 8989A, 89A or ICAP-III. SDLM1 refers to the first SDLM conducted within the periods considered. Likewise, SDLM2 is the second such SDLM. A WCS replacement is the WCS service. Modifying a Block-82 aircraft to the Block-89A configuration is the 8989A service. The Block-89 to Block-89A modification is the 89A service. The ICAP-III service modifies an aircraft to the ICAP-III configuration.

Without evidence to the contrary, it is assumed that aircraft pass all ASPA inspections except the fifth. Thus, the period of the fifth ASPA inspection coincides with SDLM1 and SDLM2 requirements. As evidence contrary to this assumption is acquired, PMA-234 makes appropriate adjustments.

Both PMA-234 and EDMOM assume there is no upper bound on the total SDLM inductions per fiscal year. In an attempt to reduce the variation in PAA inventory between fiscal years, PMA-234 has adopted a "Level Loading" policy. This policy attempts to limit total SDLM inductions to 15 per fiscal year. EDMOM implements this policy by incurring a penalty for each SDLM1 or SDLM2 induction recommended above this limit; the penalty is progressively higher for each induction exceeding 15. For example, the penalty for the 16<sup>th</sup> SDLM is 10 months, for the 17<sup>th</sup> SDLM is 11 months and so on.

A varying number of WCS, 8989A, 89A and ICAP-III service components become available during each period in accordance with predetermined delivery schedules. Contracts for delivery schedules are let far in advance of determining which aircraft will receive specific service components. Shelving of these components allows usage when optimally desired. Additionally, induction can occur a few months prior to availability of a service component. For example, an induction for a WCS two months prior to availability of a wing allows time for removal of the old wing in preparation for the new wing.

Aircraft may be partitioned into sets based on service eligibility. The SDLM1 eligible set includes all aircraft. Aircraft with SDLM2 calculated to occur within the periods considered define the SDLM2 set. The number of aircraft in the WCS eligible set is limited to the total number of WCS service components available with membership based on the order aircraft reach 95 percent FLE. Block-82 aircraft encompass the 8989A eligible set. Aircraft in a Block-89 configuration occupy the 89A set. The ICAP-III eligible set includes all aircraft.

Services fall into two categories: required and desired. The required services are SDLM1, SDLM2 and WCS. The desired services are 8989A, 89A and ICAP-III. Aircraft eligible for a required service must be inducted to receive that service. Aircraft eligible for a desired service should be inducted to receive that service if the service is available.

An option indicates the service or multiple services to be performed during a single induction. The consecutive natures of SDLM1/SDLM2 and major modifications limit possible service combinations. For example, SDLM1 and SDLM2 will never be in the same option. Likewise, 8989A and 89A will not be in the same option. Table 1 shows all possible options with associated services and approximate time required to perform the option.

OPTION	SERVICES	TIME (months)	OPTION	SERVICES	TIME (months)
1	SDLM1	12	19	89A, ICAP-III	9
2	SDLM2	12	20	SDLM1, WCS, 8989A	14
3	WCS	10	21	SDLM1, WCS, 89A	14
4	8989A	9	22	SDLM1, WCS, ICAP-III	14
5	89A	5	23	SDLM1, 8989A, ICAP-III	16
6	ICAP-III	6	24	SDLM1, 89A, ICAP-III	14
7	SDLM1, WCS	12	25	SDLM2, WCS, 8989A	14
8	SDLM1, 8989A	12	26	SDLM2, WCS, 89A	14
9	SDLM1, 89A	12	27	SDLM2, WCS, ICAP-III	14
10	SDLM1, ICAP-III	13	28	SDLM2, 8989A, ICAP-III	16
11	SDLM2, WCS	12	29	SDLM2, 89A, ICAP-III	14
12	SDLM2, 8989A	12	30	WCS, 8989A, ICAP-III	10
13	SDLM2, 89A	12	31	WCS, 89A, ICAP-III	10
14	SDLM2, ICAP-III	13	32	SDLM1, WCS, 8989A, ICAP-III	16
15	WCS, 8989A	10	33	SDLM1, WCS, 89A, ICAP-III	14
16	WCS, 89A	10	34	SDLM2, WCS, 8989A, ICAP-III	16
17	WCS, ICAP-III	10	35	SDLM2, WCS, 89A, ICAP-III	14
18	8989A, ICAP-III	9			

**Table 1.** All possible options with associated services and approximate time required to complete the option [Ellis and Tierney, 1999]. Since services within an option may be performed in parallel, the time required for an option is less than the sum of the times required to perform all services in the option.

The ICAP-III service builds on the Block-89A modification. Thus, Block-82 and Block-89 configured aircraft can not be inducted for an option including ICAP-III unless the option also includes 8989A or 89A.

An aircraft can receive a service only during a set of periods. For SDLM1, this set includes periods from six months prior to three months after the anticipated fifth ASPA inspection. The set of available periods for SDLM2 is based on the period an aircraft completes SDLM1. For a WCS, available periods include the projected periods that a wing will have between 95 and 100 percent FLE. Aircraft that have not received 8989A, 89A or ICAP-III services are always available for these services. The set of available periods for an option is based on the intersection of periods an aircraft is available to receive all services included in the option.

EDMOM minimizes the total time aircraft are removed from PAA inventory while encouraging inductions to occur as soon as possible. This is done via a penalty function equal to the time required to perform an option plus a scaled value of the difference between the recommended period and earliest period available for that option. By scaling this difference by 0.01, precedence is set to reducing the total time aircraft are removed from PAA inventory over recommending inductions occur as soon as possible. For example, assume EDMOM recommends Option 3 (WCS) for an aircraft three periods after expending 95 percent FLE and that Option 3 takes 10 periods, then a penalty of 10.03 periods is incurred.

EDMOM prefers inductions in the earliest period available because this will provide the most flexibility; inductions not found appropriate in the future can simply be

delayed as necessary. Additionally, this preference can provide a gauge to encourage persistence [Brown, Dell and Wood, 1997].

EDMOM limits the time between completion of an induction and the successive induction to be greater than a desired threshold (notionally 12 months) or a penalty is incurred. This prevents irrational scenarios such as inducing an aircraft for an 8989A two months after completing a WCS induction. From the perspective of the squadron receiving this aircraft following the WCS induction, two months is barely enough time to conduct required acceptance inspections, correct discrepancies and hone the aircraft to squadron standards.

The EA-6B attrition rate is estimated to be 1.0 percent of the total EA-6B inventory per year [OPNAV, 1999]. Since EDMOM models individual aircraft, it is impossible to directly incorporate this aggregate attrition rate. Aircraft should be deleted from EDMOM when the loss occurs.

Only two sites conduct EA-6B depot maintenance: Naval Aviation Depot, Jacksonville, Florida (NADEP JAX) and Grumman Rework Facility, St. Augustine, Florida (GSAC). It is assumed that both sites have equal service availability and time duration for options. EDMOM treats both facilities as a single, aggregated entity.



## B. MODEL FORMULATION

This section shows the indices, sets, data, decision variables and mathematical formulation of EDMOM. Where appropriate, objective function coefficients have a time index to allow time-based discounting.

### Indices:

a	aircraft	(e.g., 156481,158029,...,164403);
e	extra SDLMs	(e.g., e1,e2,...,e20);
o	option	(e.g., Option1,Option2,...,Option35);
p	period	(e.g., Oct98,Nov98,...,Sep15);
s	service	(e.g., SDLM1,SDLM2,WCS,8989A,89A,ICAP-III); and
y	fiscal year	(e.g., FY99,FY00,...,FY15).

### Sets:

AvailSet <sub>a,o</sub>	Periods aircraft "a" is available for option "o";
EligSet <sub>s</sub>	Aircraft eligible for service "s";
FySet <sub>y</sub>	Periods in fiscal year "y";
OptSet <sub>s</sub>	Options that include service "s"; and
SDLM2Set <sub>a,o,o',p</sub>	Periods aircraft "a" is available for option "o'" that includes SDLM2 if inducted for option "o" that included SDLM1 in period "p".

**Data:**

$\text{delay}_{a,o,p}$	Discounted penalty for inducing aircraft "a" for option "o" in period "p" (periods);
$\text{deliv}_{p,s}$	Number of service "s" components that become available in period "p" (aircraft);
$\text{indEarly}_s$	Maximum number of periods before availability of service "s" components that an aircraft may be inducted to use those components (periods);
$\text{indLate}_s$	Maximum number of periods after availability of service "s" components that an aircraft may be inducted to use those components (periods);
$\text{minOp}$	Minimum number of periods between the completion of an induction and the successive induction (periods);
$\text{sdImPen}_{e,y}$	Discounted penalty for the $e^{\text{th}}$ SDLM above the targeted number of SDLM inductions in fiscal year "y" (periods);
$\text{tgtSDLM}$	Targeted number of SDLM inductions per fiscal year (aircraft); and
$\text{time}_o$	Number of periods required to perform option "o" (period).

**Decision Variables:**

$\text{INDUCT}_{a,o,p}$	One if aircraft "a" is inducted for option "o" during period "p", zero otherwise (binary);
$\text{SDLM}_{e,y}$	One if the $e^{\text{th}}$ SDLM above the targeted number of SDLM inductions per fiscal year is scheduled during fiscal year "y", zero otherwise (positive variable); and
$\text{VIOMINOP}_a$	Number of times aircraft "a" violates the minimum number of periods between the completion of an induction and the successive induction (positive variable).

## Mathematical Formulation:

Minimize the Objective Function...

$$\sum_a \sum_o \sum_p \text{delay}_{a,o,p} * \text{INDUCT}_{a,o,p} + \sum_e \sum_y \text{sdlmPen}_{e,y} * \text{SDLM}_{e,y} + \sum_a \text{minOp} * \text{VIOMINOP}_a \quad (\text{Obj.})$$

Subject to...

$$\sum_{o \in \text{OptSet}_s} \sum_{p \in \text{AvailSet}_{a,o}} \text{INDUCT}_{a,o,p} \geq 1 \quad \forall s \in \{\text{SDLM1}, \text{WCS}\}, a \in \text{EligSet}_s \quad (\text{C1})$$

$$\text{INDUCT}_{a,o,p} \leq \sum_{o' \in \text{OptSet-SDLM2}} \sum_{p' \in \text{SDLM2Set}_{a,o,o',p}} \text{INDUCT}_{a,o',p'} \quad \forall a \in \text{EligSet-SDLM2}, o \in \text{OptSet-SDLM1}, p \quad (\text{C2})$$

$$\sum_{o \in \text{OptSet}_s} \sum_{p \in \text{AvailSet}_{a,o}} \text{INDUCT}_{a,o,p} \leq 1 \quad \forall a, s \quad (\text{C3})$$

$$\sum_a \sum_{o \in \{\text{OptSet-SDLM1} \cup \text{OptSet-SDLM2}\}} \sum_{p \in \text{FySet}_y} \text{INDUCT}_{a,o,p} \leq \text{tgtSDLM} + \sum_e \text{SDLM}_{e,y} \quad \forall y \quad (\text{C4})$$

$$\sum_a \sum_{o \in \text{OptSet}_s} \sum_{p' \leq p} \text{INDUCT}_{a,o,p'} \leq \sum_{p' \leq p + \text{indEarly}_s} \text{deliv}_{p',s} \quad \forall p, s \in \{\text{WCS}, 8989\text{A}, 89\text{A}, \text{ICAP-III}\} \quad (\text{C5})$$

$$\sum_a \sum_{o \in \text{OptSet}_s} \sum_{p' \geq p} \text{INDUCT}_{a,o,p'} \leq \sum_{p' \geq p - \text{indLate}_s} \text{deliv}_{p',s} \quad \forall p, s \in \{\text{WCS}, 8989\text{A}, 89\text{A}, \text{ICAP-III}\} \quad (\text{C6})$$

**Mathematical Formulation (continued):**

$$\sum_a \sum_{o \in \text{OptSet}_s} \sum_p \text{INDUCT}_{a,o,p} = \sum_p \text{deliv}_{p,s} \quad \forall s \in \{8989A, 89A, \text{ICAP-III}\} \quad (\text{C7})$$

$$\sum_{o \in \text{OptSet}_s} \sum_{p \leq p} \text{INDUCT}_{a,o,p} \geq \sum_{o \in \text{OptSet}_{\text{ICAP-III}}} \text{INDUCT}_{a,o,p} \quad \forall s \in \{8989A, 89A\},$$

$$a \in \{\text{EligSet}_s \cap \text{EligSet}_{\text{ICAP-III}}\}, p \quad (\text{C8})$$

$$\sum_o \sum_{p=p-\text{minOp-time}_o+1}^p \text{INDUCT}_{a,o,p} \leq 1 + \text{VIOMINOP}_a \quad \forall a, p \quad (\text{C9})$$

$$\text{INDUCT}_{a,o,p} \in \{0,1\} \quad \forall a, o, p \quad (\text{CA})$$

$$0 \leq \text{SDLM}_{e,y} \leq 1 \quad \forall e, y \quad (\text{CB})$$

$$\text{VIOMINOP}_a \geq 0 \quad \forall a \quad (\text{CC})$$

## EXPLANATION OF THE MATHEMATICAL FORMULATION:

The first objective function term measures the number of periods aircraft are removed from PAA inventory to perform an option plus a scaled value of the difference between the recommended period and earliest period available for that option. The second term gauges the number of SDLMs EDMOM recommends above a desired threshold. The third term penalizes each aircraft that violates the desired minimum periods between inductions.

Constraint (C1) ensures compliance with required SDLM1 and WCS inductions. Constraint (C2) ensures required SDLM2 inductions. Constraint (C3) ensures aircraft receive no more than one induction of each service. Constraint (C4) counts SDLM inductions above a desired threshold. Constraint (C5) limits the amount of time prior to availability of service components that an induction may occur. Constraint (C6) restricts the time service components can be inventoried. Constraint (C7) ensures utilization of all 8989A, 89A and ICAP-III service components. Constraint (C8) does not allow an ICAP-III induction before 8989A or 89A inductions. Constraint (C9) ensures a minimum time between successive inductions. Constraint (CA) establishes  $\text{Induct}_{a,o,p}$  as a binary variable. Constraint (CB) sets upper and lower bounds on  $\text{SDLM}_{e,y}$ . Constraint (CC) established  $\text{VIOMINOP}_a$  as a non-negative variable.

## C. SET DERIVATIONS

This section shows the derivation of two kingpin sets: AvailSet<sub>a,o</sub> and SDLM2Set<sub>a,o,o',p</sub>. Prior to deriving these however, we require additional sets and data.

### 1. Additional Sets and Data

#### Sets:

ASPA1Set <sub>a</sub>	Periods aircraft "a" is available for its first through fifth ASPA inspection prior to SDLM1;
ASPA2Set <sub>a</sub>	Periods aircraft "a" is available for its first through fifth ASPA inspection after SDLM1;
OperSet <sub>s</sub>	Periods service "s" is available;
PdSet <sub>a,s</sub>	Periods aircraft "a" is available for service "s"; and
ServSet <sub>o</sub>	Services included in option "o".

#### Data:

aspaOne	Number of periods between completion of SDLM1 and first ASPA inspection (periods);
aspaPd	Number of periods between first through fifth ASPA inspections (periods);
early <sub>a,s</sub>	Number of periods before serv <sub>a,s</sub> aircraft "a" can receive service "s" (periods);
late <sub>a,s</sub>	Number of periods after serv <sub>a,s</sub> aircraft "a" can receive service "s" (periods);
maxSDLM	Maximum number of periods required to complete any induction involving SDLM1 or SDLM2 (periods);
minSDLM	Minimum number of periods required to complete any induction involving SDLM1 or SDLM2 (periods); and

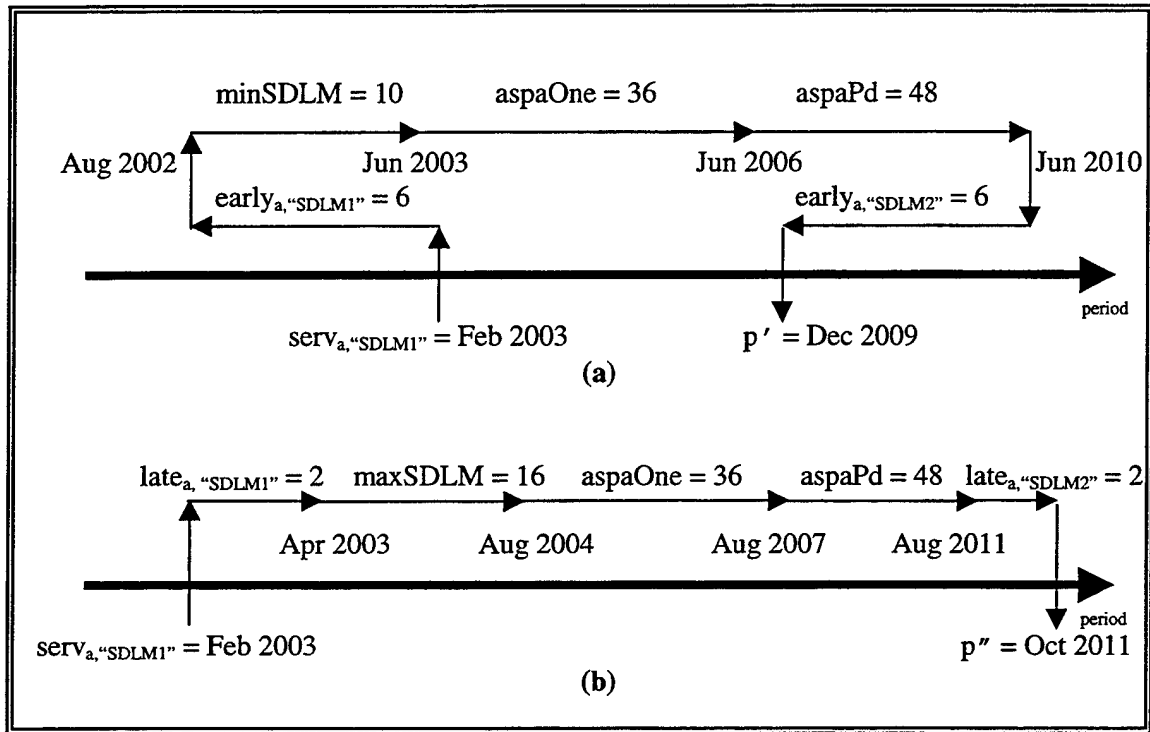
**Data (continued):**

$\text{serv}_{a,s}$       Period aircraft “a” is due for service “s” (period)  
 (e.g.,  $\text{serv}_{a,\text{“SDLM1”}}$  = Period of fifth ASPA inspection for aircraft  
 “a”; and  
 $\text{serv}_{a,\text{“WCS”}}$  = Period aircraft “a” reaches 95 percent FLE.).

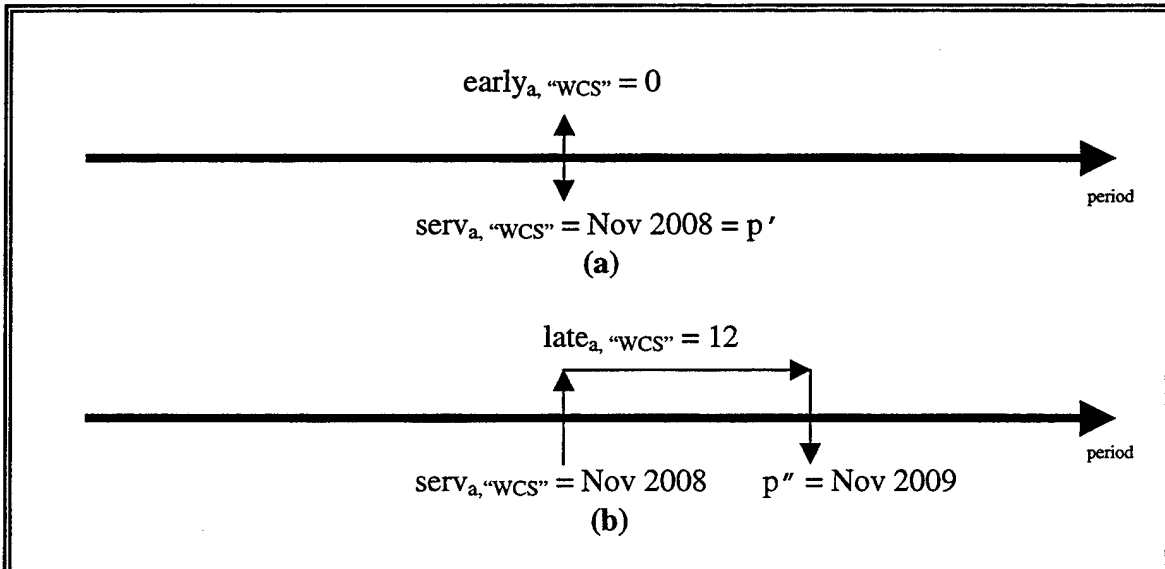
Using the Additional Data,

$$\text{PdSet}_{a,s} = \begin{cases} \{\text{serv}_{a,s} - \text{early}_{a,s}, \dots, \text{serv}_{a,s} + \text{late}_{a,s}\} & \forall s \in \{\text{SDLM1}, \text{WCS}\}, a \in \text{EligSet}_s, \\ \{\text{serv}_{a,\text{“SDLM1”}} - \text{early}_{a,\text{“SDLM1”}} + \text{minSDLM} + \text{aspaOne} + \text{aspaPd} - \text{early}_{a,s}, \dots, \\ \quad \text{serv}_{a,\text{“SDLM1”}} + \text{late}_{a,\text{“SDLM1”}} + \text{maxSDLM} + \text{aspaOne} + \text{aspaPd} + \text{late}_{a,s}\} & \forall s = \text{SDLM2}, a \in \text{EligSet}_s, \\ \{\text{present}, \dots, \text{Sep15}\} & \forall s \in \{8989\text{A}, 89\text{A}, \text{ICAP} - \text{III}\}, a \in \text{EligSet}_s, \\ \{\} & \text{otherwise.} \end{cases}$$

As an example, Figure 4 shows  $\text{PdSet}_{a,s}$  for fictitious aircraft  $a=123456$  with service  $s=\text{SDLM2}$  includes periods ranging from December 2009 and October 2011. Figure 5 shows  $\text{PdSet}_{\text{“123456”, “WCS”}}$  includes periods between November 2008 and November 2009.



**Figure 4.**  $PdSet_{a,s}$  for fictitious aircraft  $a=123456$  with service  $s=SDLM2$ . (a) Shows  $p'$ ; the earliest period in  $PdSet_{a, 'SDLM2'}$ . (b) Shows  $p''$ ; the latest period in  $PdSet_{a, 'SDLM2'}$ . (Not to scale.)



**Figure 5.**  $PdSet_{a,s}$  for fictitious aircraft  $a=123456$  with service  $s=WCS$ . (a) Shows  $p'$ ; the earliest period in  $PdSet_{a, 'WCS'}$ . (b) Shows  $p''$ ; the latest period in  $PdSet_{a, 'WCS'}$ . (Not to scale.)



OperSet<sub>s</sub> defines possible induction periods for a specific service. With the exception of ICAP-III, depots presently conduct all services. SDLM1 and SDLM2 are currently expected to continue until the EA-6B is retired. WCS services will end in FY-09, 8989As end in FY-04 and FY-02 marks the end of 89As. ICAP-III is currently under development with the first prototype aircraft induction expected in November 1999. The last ICAP-III service is anticipated to occur in FY-12. Using this information,

$$\text{OperSet}_s = \begin{cases} \{\text{present}, \dots, \text{Sep2015}\} & s = \text{SDLM1}, \text{SDLM2}, \\ \{\text{present}, \dots, \text{Sep2009}\} & s = \text{WCS}, \\ \{\text{present}, \dots, \text{Sep2004}\} & s = 8989A, \\ \{\text{present}, \dots, \text{Sep2002}\} & s = 89A, \\ \{\text{Nov1999}, \dots, \text{Sep2012}\} & s = \text{ICAP - III}. \end{cases}$$

Aircraft inducted for a WCS may receive a concurrent SDLM1 or SDLM2 if it has surpassed its first ASPA inspection. This relaxation of the requirement for SDLMs based on failure of the fifth ASPA inspection has the potential of reducing the number of required inductions. ASPA1Set<sub>a</sub> and ASPA2Set<sub>a</sub> reflect this relaxation; PdSet<sub>a</sub>, "SDLM1" and PdSet<sub>a</sub>, "SDLM2" are subsets of ASPA1Set<sub>a</sub> and ASPA2Set<sub>a</sub>. Mathematically,

$$\text{ASPA1Set}_a = \{\text{serv}_{a,s} - \text{early}_{a,s} - \text{aspaPd}, \dots, \text{serv}_{a,s} + \text{late}_{a,s}\} \quad \forall s = \text{SDLM1}, a \in \text{EligSet}_s ;$$

and

$$\begin{aligned} \text{ASPA2Set}_a = \{ & \text{serv}_{a, \text{"SDLM1"}} - \text{early}_{a, \text{"SDLM1"}} + \text{minSDLM} + \text{aspaOne} - \text{early}_{a,s}, \dots, \\ & \text{serv}_{a, \text{"SDLM1"}} + \text{late}_{a, \text{"SDLM1"}} + \text{maxSDLM} + \text{aspaOne} + \text{aspaPd} + \text{late}_{a,s} \} \\ & \forall s = \text{SDLM2}, a \in \text{EligSet}_s. \end{aligned}$$

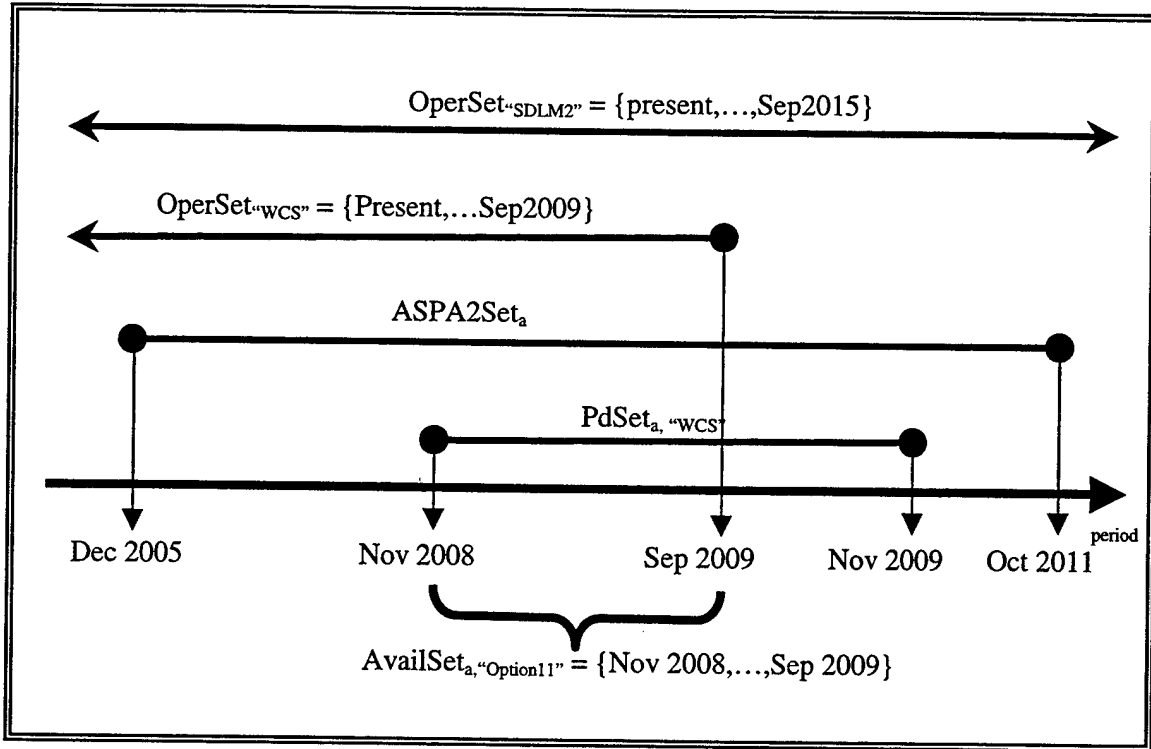
For aircraft a=123456, ASPA2Set<sub>a</sub> contains periods ranging from December 2005 to October 2011.

## 2. Derivation of AvailSet<sub>a,o</sub>

With PdSet<sub>a,s</sub>, OperSet<sub>s</sub>, ASPA1Set<sub>a</sub> and ASPA2Set<sub>a</sub> defined, it is possible to mathematically define AvailSet<sub>a,o</sub>:

$$\text{AvailSet}_{a,o} = \begin{cases} \bigcap_{s \in \text{ServSet}_o} \text{PdSet}_{a,s} \bigcap_{s \in \text{ServSet}_o} \text{OperSet}_s & \forall a, o \mid \{\text{WCS}, \text{SDLM1}\}, \{\text{WCS}, \text{SDLM2}\} \not\subset \text{ServSet}_o, \\ \bigcap_{\substack{s \in \text{ServSet}_o \\ s \neq \text{SDLM1}}} \text{PdSet}_{a,s} \bigcap_{s \in \text{ServSet}_o} \text{OperSet}_s \cap \text{ASPA1Set}_a & \forall a, o \mid \{\text{WCS}, \text{SDLM1}\} \subset \text{ServSet}_o, \\ \bigcap_{\substack{s \in \text{ServSet}_o \\ s \neq \text{SDLM2}}} \text{PdSet}_{a,s} \bigcap_{s \in \text{ServSet}_o} \text{OperSet}_s \cap \text{ASPA2Set}_a & \forall a, o \mid \{\text{WCS}, \text{SDLM2}\} \subset \text{ServSet}_o. \end{cases}$$

Continuing the aircraft a=123456 example, it is now possible to show AvailSet<sub>a,o</sub> for o=Option 11 (SDLM2 and WCS). Figure 6 shows the periods in AvailSet<sub>“123456”,“Option11”</sub> range from November 2008 to September 2009. Without the relaxation provided by ASPA2Set<sub>a</sub>, AvailSet<sub>“123456”,“Option11”</sub> would be empty due to PdSet<sub>“123456”,“SDLM2”</sub> (December 2009 to October 2011) and PdSet<sub>“123456”,“WCS”</sub> (November 2008 to November 2009) being disjoint.



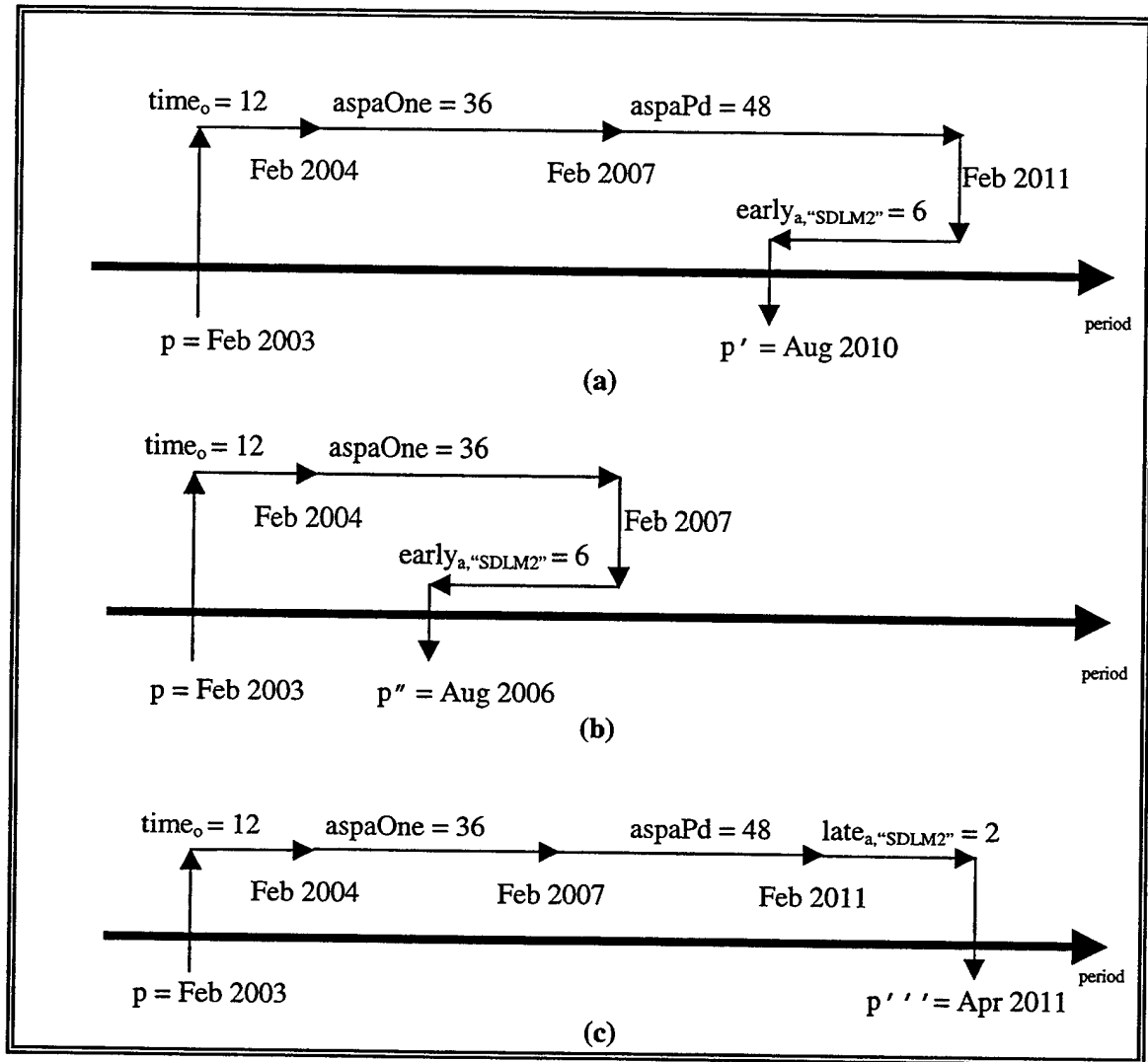
**Figure 6.**  $\text{AvailSet}_{a,o}$  for fictitious aircraft  $a=123456$  with option  $o=\text{Option 11}$  using previously determined values for  $\text{OperSet}_{\text{SDLM2}}$ ,  $\text{OperSet}_{\text{WCS}}$ ,  $\text{ASPA2Set}_a$  and  $\text{PdSet}_{a, \text{'WCS'}}$ . (Not to scale.)

### 3. Derivation of $\text{SDLM2Set}_{a,o,o',p}$

Based on the period an aircraft is inducted for SDLM1, it is possible to refine the periods available for SDLM2. Recall that  $\text{SDLM2Set}_{a,o,o',p}$  is the periods aircraft “a” is available for option “o’” that includes SDLM2 if inducted for option “o” that included SDLM1 in period “p”. Mathematically,

$$\text{SDLM2Set}_{a,o,o',p} = \begin{cases} \{p + \text{time}_o + \text{aspaOne} + \text{aspaPd} - \text{early}_{a,\text{"SDLM2"}}, \dots, \\ \quad p + \text{time}_o + \text{aspaOne} + \text{aspaPd} + \text{late}_{a,\text{"SDLM2"}}\} \\ \quad \forall a \in \text{EligSet}_{\text{"SDLM2"}}, o \in \text{OptSet}_{\text{"SDLM1"}}, \\ \quad o' \in \{\text{OptSet}_{\text{"SDLM2"}} - \text{OptSet}_{\text{"WCS"}}\}, p; \\ \\ \{p + \text{time}_o + \text{aspaOne} - \text{early}_{a,\text{"SDLM2"}}, \dots, \\ \quad p + \text{time}_o + \text{aspaOne} + \text{aspaPd} + \text{late}_{a,\text{"SDLM2"}}\} \\ \quad \forall a \in \{\text{EligSet}_{\text{"SDLM2"}} \cap \text{EligSet}_{\text{"WCS"}}\}, \\ \quad o \in \{\text{OptSet}_{\text{"SDLM1"}} - \text{OptSet}_{\text{"WCS"}}\}, \\ \quad o' \in \{\text{OptSet}_{\text{"SDLM2"}} \cap \text{OptSet}_{\text{"WCS"}}\}, p; \\ \\ \{\} \quad \text{otherwise.} \end{cases}$$

To demonstrate  $\text{SDLM2Set}_{a,o,o',p}$  for aircraft  $a=123456$ , assume it is inducted for  $o=\text{Option 1 (SDLM1)}$  on the period of its fifth ASPA inspection,  $p=\text{Febuary 2003}$ . Under this assumption, Figure 7 shows aircraft  $a=123456$  available for  $o'=\text{Option 2 (SDLM2)}$  from August 2010 to April 2011 and  $o'=\text{Option 11 (SDLM2, WCS)}$  from August 2006 to April 2011. Both being subsets of  $\text{ASPA2Set}_{\text{"123456"}}$  (December 2005 to October 2011).



**Figure 7.**  $SDLM2SET_{a,o,o',p}$  for fictitious aircraft  $a=123456$  with  $o=Option\ 1$  (SDLM1) and  $p=Feb\ 2003$ . (a) Shows  $p'$ ; the earliest period in  $SDLM2SET_{a,o,o',p}$  if  $o'=Option\ 2$  (SDLM2). (b) Shows  $p''$ ; the earliest period in  $SDLM2SET_{a,o,o',p}$  if option  $o'=Option\ 11$  (SDLM2, WCS). (c) Shows  $p'''$ , the latest period in  $SDLM2SET_{a,o,o',p}$  if option  $o'$  includes a SDLM2. (Not to scale.)

#### **IV. IMPLEMENTATION AND COMPUTATIONAL RESULTS**

This chapter provides an overview of the EA-6B fleet, service component availability and results of implementing EDMOM with a planning horizon of FY-09. The flexibility provided by EDMOM to explore various depot maintenance scenarios is also demonstrated.

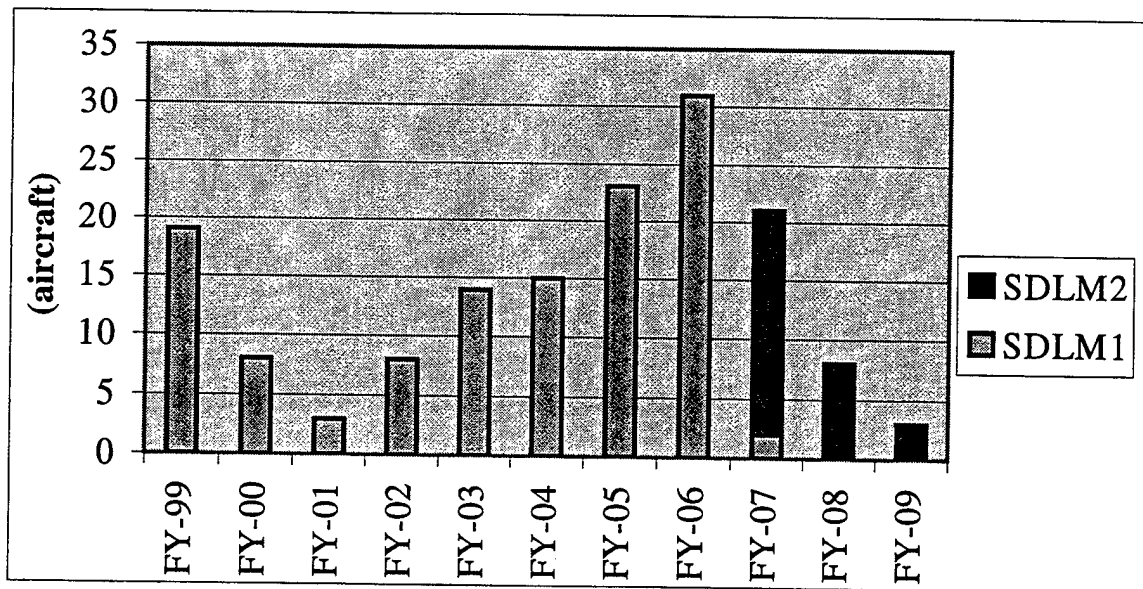
##### **A. EA-6B FLEET AND SERVICE COMPONENT AVAILABILITY**

SEMCOR provided all data needed for implementing EDMOM [Ellis and Tierney, 1999]. Under contract with PMA-234 and using the same data, SEMCOR helps PMA-234 create the Master Plan.

Of the 170 EA-6B aircraft manufactured, only 123 remain. Of these remaining aircraft, 66 are Block-82 configuration, 53 have the Block-89 configuration and only 4 have been modified to Block-89A. The USMC is assigned 18 EA-6B aircraft with the balance assigned to the USN. The majority, 103 aircraft, have wings constructed of T-7050.

Due to the recurrent nature of SDLM, all aircraft will require a SDLM1 by FY-09. Recalling ASPA failure typically occurs seven years after the completion of a SDLM and that an induction involving a SDLM takes approximately one year, the time between SDLM1 and SDLM2 inductions is calculated to be approximately eight years. For example, aircraft inducted for SDLM1 in FY-99 have SDLM2 inductions projected to occur in FY-07. For implementation, only aircraft with SDLMs predicted in FY-99, FY-00

or FY-01 will be included in the set of aircraft requiring SDLM2. As shown in Figure 8, an impending bow wave of SDLM inductions is projected to begin in FY-05.



**Figure 8.** The number of predicted SDLM inductions per fiscal year based on anticipated failure of the fifth Aircraft Service Period Adjustment (ASPA) inspection. SDLM includes either the SDLM1 or SDLM2 service.

The WCS replacement schedule is based on when aircraft reach 95 percent FLE. Under current projections, only 80 WCS replacements will occur during the remaining service life of the EA-6B. Thus, the first 80 aircraft to reach 95 percent FLE will receive a WCS replacement. Aircraft not receiving a WCS replacement will be managed to ensure 100 percent FLE is not expended before aircraft retirement. The 80<sup>th</sup> aircraft will reach 95 percent FLE in FY-08. Table 2 shows the expected fiscal year availability profile for WCS, 8989A, 89A and ICAP-III service components. Being a prototype modification, the expected availability of ICAP-III components remains highly speculative.

Fiscal Year	WCS Components	8989A Components	89A Components	ICAP-III Components
FY-99	9	8	1	-
FY-00	-	6	12	2
FY-01	5	9	8	-
FY-02	10	14	8	-
FY-03	10	12	-	8
FY-04	9	-	-	8
FY-05	9	-	-	8
FY-06	9	-	-	10
FY-07	9	-	-	10
FY-08	10	-	-	10
FY-09	-	-	-	10

**Table 2.** The number of service components that become available during a given Fiscal Year. Shelving of these components allows usage when optimally desired. Induction can also occur a few months prior to availability of the service component.

## B. IMPLEMENTATION OF EDMOM

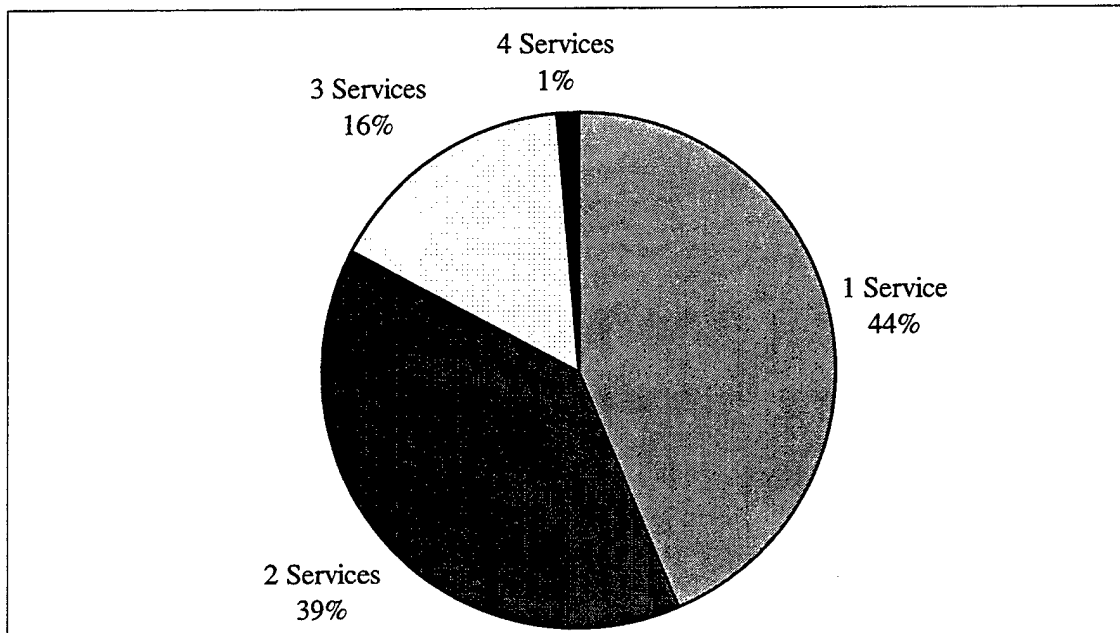
This section overviews the result of implementing EDMOM in the General Algebraic Modeling System (GAMS), release 2.50.94 [Brooke, A., et al., 1997] when calling the CPLEX 6.0 solver [ILOG, 1997]. Default CPLEX parameters were modified to ensure the linear program relaxation was solved using the dual simplex method, branching variable selection was based on pseudo-shadow prices and backtracking node selection was done via best-estimated search. Considering all 123 EA-6B aircraft on a 10.5-year planning horizon at monthly resolution, with a yearly discount rate of 0.1, GAMS generated approximately 31,500 equations, 34,400 binary variables, 400 continuous variables and 6,500,000 non-zero elements. With an integrality gap of eight percent, CPLEX found a solution in 13.6 CPU minutes on a Pentium-II, 300-MHz, 512-MB



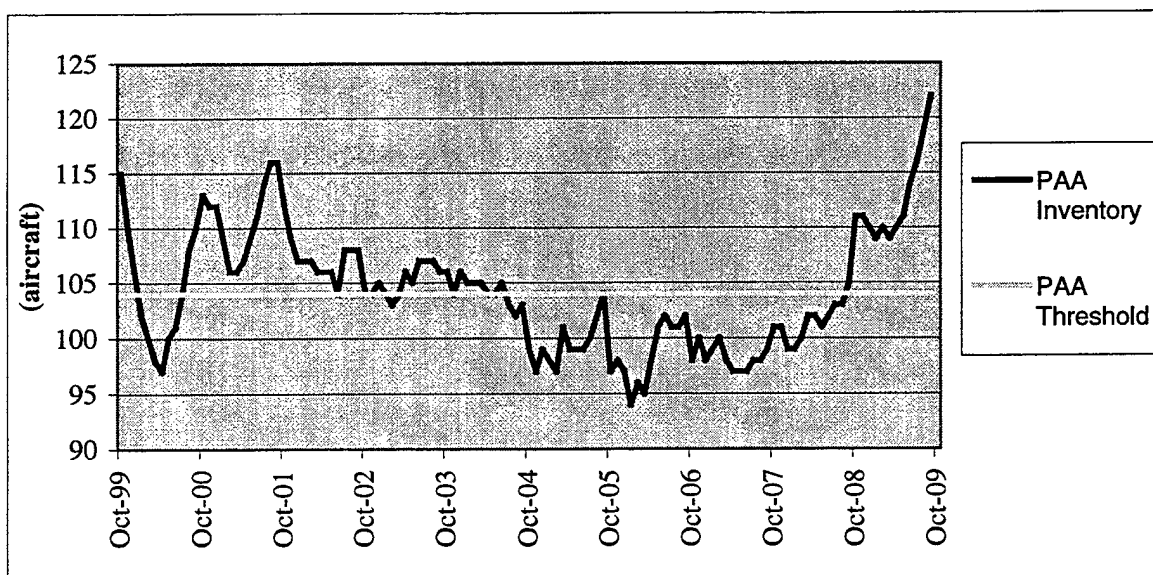
computer. Appendix B provides EDMOM's recommended induction schedule for each EA-6B through FY-09.

To allow a dovetailing of the Master Plan with EDMOM's recommendations, EDMOM uses the Master Plan's FY-99 induction schedule. EDMOM also uses PMA-234's ICAP-III prototype plan, inducting aircraft 156481 for Option 10 in November 1999 and aircraft 159909 for Option 6 in June 2000 [Ellis and Tierney, 1999].

As identified by the OAG, a primary means to reduce time aircraft are removed from PAA inventory is to combine services. Allowing inductions between two months prior and nine months after service component availability, EDMOM recommended 378 services in only 216 inductions, requiring 2,446 total months. Without combining services, it would require 3,630 months, nearly a 50 percent increase. As shown in Figure 9, 56 percent of the inductions recommended by EDMOM contained two or more services. Unfortunately, combining services is not enough to eliminate all shortages in PAA inventory; Figure 10 shows PAA inventory drops below the desired 104 aircraft threshold 47 percent of the time. However, the average monthly PAA inventory, 104.24 aircraft, is above the desired 104 aircraft threshold.

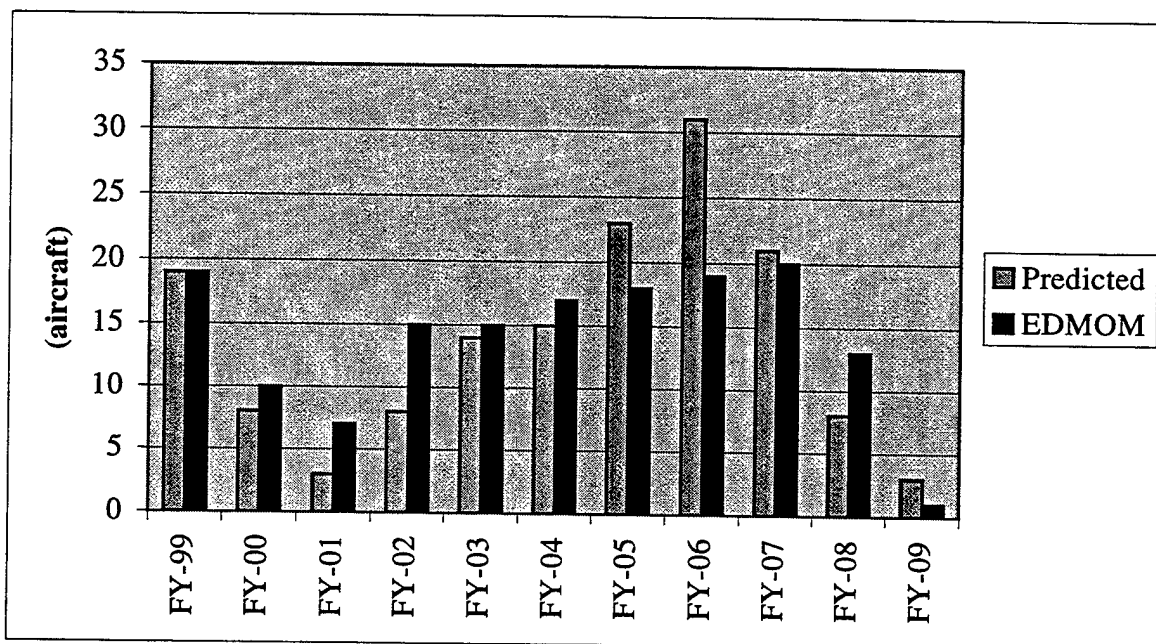


**Figure 9.** The percentage of recommended inductions that include 1, 2, 3 or 4 services. By combining services into options, EDMOM recommended 378 services in only 216 inductions.



**Figure 10.** The desired 104 aircraft PAA threshold and the number of EA-6B aircraft in PAA inventory utilizing EDMOMS recommended induction schedule. Annual EA-6B attrition rate was not used to calculate PAA inventory.

PMA-234's "Level Loading" policy coupled with allowing concurrent SDLM1 or SDLM2 with WCS services, when an aircraft has surpassed its first ASPA inspection, assisted EDMOM in reducing both the variation and peak value of the impending bow wave of projected SDLM inductions described in the previous section. As shown in Figure 11, EDMOM reduced the peak value by more than 10 SDLM inductions.

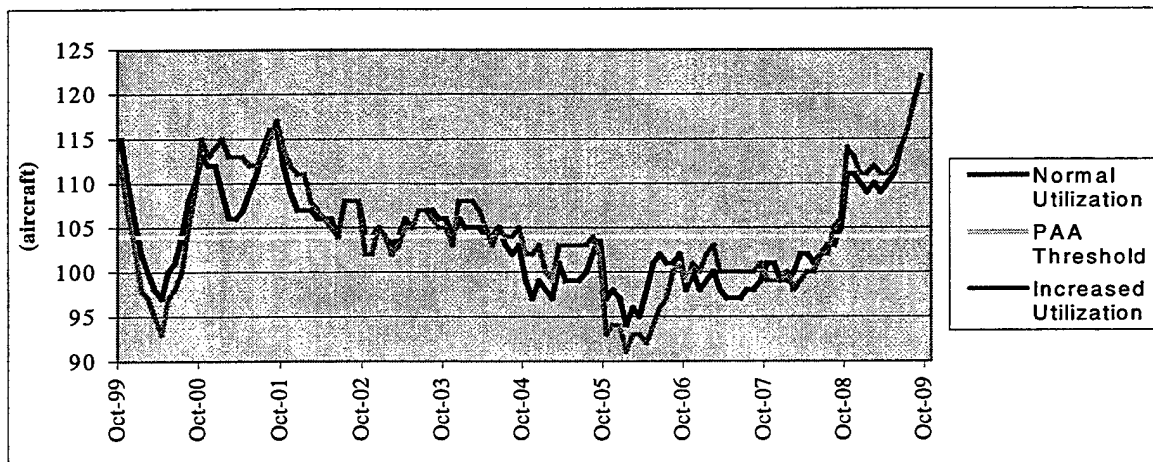


**Figure 11.** The number of predicted SDLM inductions and EDMOM's recommended SDLM inductions. PMA-234's "Level Loading" policy assisted EDMOM in reducing both the variation and peak value of the bow wave of SDLM inductions.

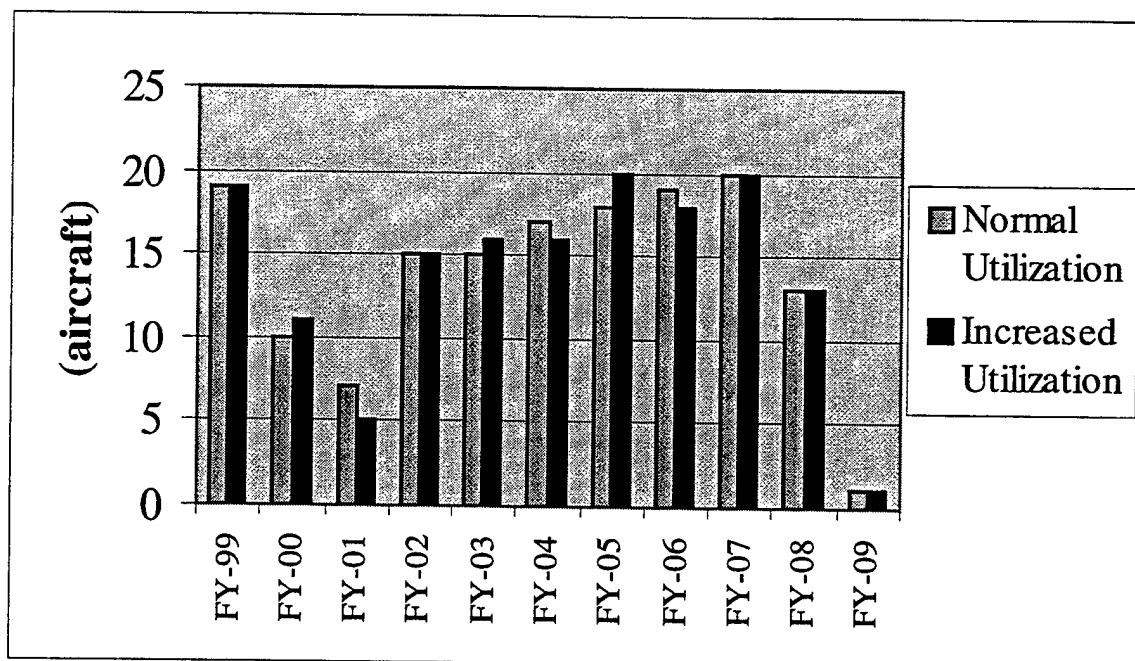
### C. MODEL FLEXIBILITY

An often-overlooked byproduct of combat operations is an increased operational use of aircraft. For example, combat operations in the Balkans resulted in the average PAA EA-6B flying 57.2 hours in May 1999 [Ellis and Tierney, 1999]. This is over double the projected overall EA-6B utilization rate of 25.5 hours per month [OPNAV, 1999]. If

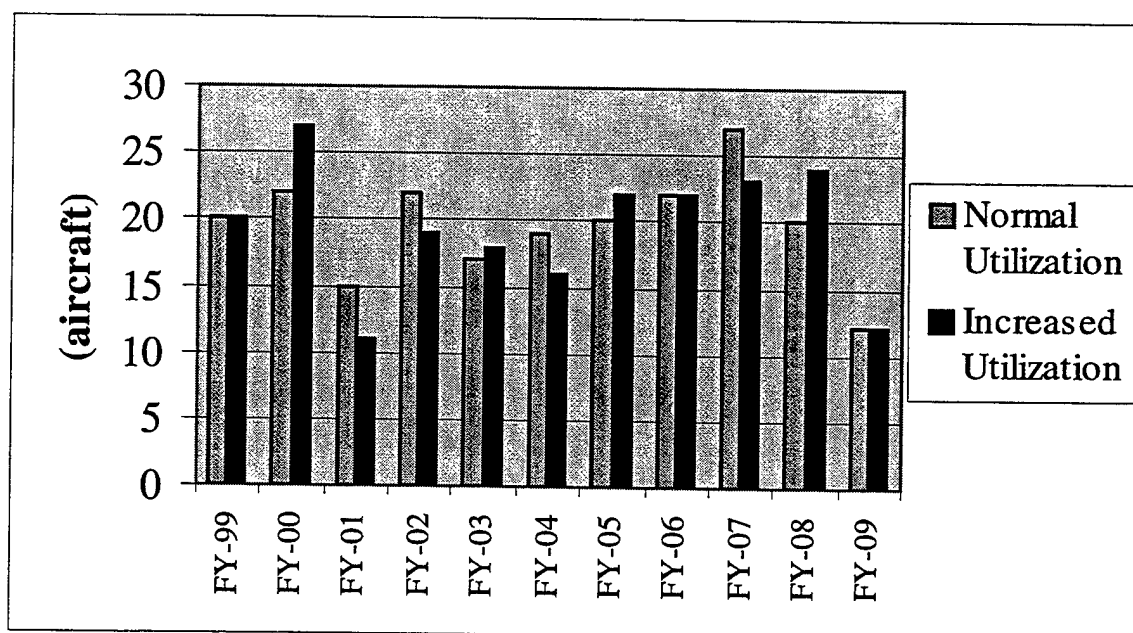
sustained for six months, such an increased utilization rate would result in aircraft reaching 95 percent FLE six months earlier than anticipated. Considering the effects of such a scenario simply requires decreasing  $serv_a$ , "WCS" by six months in the previously described implementation and re-solving the problem. In this scenario, EDMOM recommended the same 378 services but in only 214 inductions, requiring only 2,411 months. As shown in Figure 12, increased utilization drops PAA inventory below the desired 104 aircraft threshold 49 percent of the time; a two percent increase compared to normal utilization. However, with this increased utilization, the average monthly PAA inventory increased from 104.2 to 104.5 aircraft. Figure 13 compares fiscal year SDLM inductions recommended in this scenario with that of the previous section. Likewise, Figure 14 compares the total recommended inductions per fiscal year. Both Figure 13 and Figure 14 show only a slight variation in the number of inductions recommended per fiscal year; thus exhibiting EDMOM's persistence. Appendix C provides EDMOM's recommended induction schedule for this scenario.



**Figure 12.** The desired 104 aircraft PAA threshold, number of EA-6B aircraft in PAA inventory assuming a normal utilization rate and the number of EA-6B aircraft in PAA inventory when the utilization rate is doubled for a six-month period. Annual EA-6B attrition rate was not used to calculate PAA inventory.



**Figure 13.** The recommended SDLM inductions assuming a normal utilization rate and recommended SDLM inductions when the utilization rate is doubled for a six-month period. Only a slight variation in the number of inductions recommended per fiscal year is seen.



**Figure 14.** The total recommended inductions assuming a normal utilization rate and total recommended inductions when the utilization rate is doubled for a six-month period. Only a slight variation in the number of inductions recommended per fiscal year is seen.

## **V. CONCLUSION AND RECOMMENDATIONS**

### **A. CONCLUSION**

This thesis developed an optimization-based model, EDMOM, to recommend a depot maintenance induction schedule for the EA-6B. EDMOM minimizes the time aircraft are removed from PAA inventory while adhering to depot service life extension and major modification programs. Key features of the model include (i) the dexterity to combine multiple services during a single induction, (ii) the ability to reduce the magnitude of SDLM inductions per fiscal year and (iii) the flexibility to explore various depot maintenance scenarios.

The effectiveness of EDMOM is demonstrated by its implementation in GAMS with real world data. Using the CPLEX solver, EDMOM recommended conducting 378 services in only 216 inductions while reducing the maximum yearly projected SDLM inductions by over 10. By a simple modification of data, EDMOM showed the effect of increased operational use of the EA-6B.

### **B. RECOMMENDATIONS**

In an era of decreasing budgets and increasing operational commitments, the DON must make all attempts to optimally manage scarce resources. This thesis developed an optimization model to assist the EA-6B community manage one of its scarcest resources,

aircraft on the cutting edge of electronic warfare technology. PMA-234 must consider implementing such a model.

As the EA-6B rapidly approaches the end of its service life, aircraft retirement issues, such as the SDLM policy, must be addressed. Should aircraft receive SDLM's in years immediately preceding retirement? If not, when will SDLM inductions cease? It is of paramount importance that the EA-6B community answers such questions today to allow optimizing tomorrow's induction schedule.

The following list of topics is recommended to further extend this thesis.

1. De-aggregate NADEP JAX and GSAC depot sites. Specifically address individual site levels of service availability and time duration for options.
2. Enhance ease of implementation by developing a graphical user interface (GUI) for input and data modification.
3. Determine the concluding date for SDLM inductions and implement EDMOM through the EA-6B's remaining service life.

## APPENDIX A.      LIST OF ABBREVIATIONS AND ACRONYMS

ASPA	Aircraft Service Period Adjustment
Block-82	Improved Capability II/Block-82
Block-86	Improved Capability II/Block-86
Block-89	Improved Capability II/Block-89
Block-89A	Improved Capability II/Block-89A
CAG	Counting Accelerometer Group
COMVAQWINGPAC	Commander Electronic Combat Wing, U.S. Pacific Fleet
DON	Department of the Navy
EDMOM	EA-6B Depot Maintenance Optimization Model
ESC	Executive Steering Committee
EXCAP	Expanded Capability
FLE	Fatigue Life Expenditure
FY	Fiscal Year
G	Gravitational Acceleration Force
GAMS	General Algebraic Modeling System
GSAC	Grumman Rework Facility, St. Augustine, Florida
GUI	Graphical User Interface
HARM	High Speed Anti-Radiation Missile
ICAP-I	Improved Capability I
ICAP-III	Improved Capability III, also a service
IMC	Integrated Maintenance Concept
ISIS	Isochronal Scheduling Inspection System
NADEP JAX	Naval Aviation Depot, Jacksonville, Florida
NAVAIR	Naval Air Systems Command
OAG	Operational Advisory Group
OPNAV	Office of the Chief of Naval Operations
PAA	Primary Aircraft Authorization
PED	Period End Date
PMA-234	Program Manager for the EA-6B
SDLM	Standard Depot Level Maintenance
SDLM1	First SDLM service conducted within the periods considered
SDLM2	Second SDLM service conducted within the periods considered
T-7050	Type 7050 Aluminum
T-7079	Type 7079 Aluminum
USMC	United States Marine Corps
USN	United States Navy
WCS	Wing Center Section, also a service
89A	Block-89 to Block-89A modification service
8989A	Block-82 to Block-89A modification service



THIS PAGE INTENTIONALLY LEFT BLANK.

## APPENDIX B. EDMOM'S RECOMMENDED INDUCTION SCHEDULE

Tables 3 to 13 depict EDMOM's recommended induction schedule for each EA-6B through FY-09. Included are the recommended induction period, option and services included in the option.

FY-99								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158035	FY-99	1	X					
158540	FY-99	20	X		X	X		
158544	FY-99	20	X		X	X		
158810	FY-99	20	X		X	X		
158811	FY-99	20	X		X	X		
158815	FY-99	20	X		X	X		
159587	FY-99	20	X		X	X		
159908	FY-99	20	X		X	X		
159912	FY-99	1	X					
160706	FY-99	20	X		X	X		
160791	FY-99	1	X					
161775	FY-99	1	X					
163522	FY-99	1	X					
163524	FY-99	1	X					
163525	FY-99	1	X					
163527	FY-99	9	X				X	
163528	FY-99	1	X					
163886	FY-99	1	X					
163890	FY-99	1	X					
163396	FY-99	3			X			

**Table 3.** EDMOM's recommended induction schedule for FY-99. To allow a dovetailing of the Master Plan with EDMOM's recommendations, EDMOM uses the Master Plan's FY-99 induction schedule.

FY-00								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158036	Oct-99	1	X					
156481	Nov-99	10	X					X
158805	Nov-99	4				X		
162935	Nov-99	4				X		
163887	Nov-99	9	X				X	
163888	Nov-99	9	X				X	
158650	Dec-99	4				X		
158801	Dec-99	4				X		
163889	Dec-99	9	X				X	
163891	Dec-99	9	X				X	
158040	Jan-00	4				X		
158649	Jan-00	5					X	
158800	Jan-00	4				X		
161347	Jan-00	5					X	
158029	Feb-00	5					X	
164402	Feb-00	5					X	
161120	Mar-00	5					X	
163526	Mar-00	9	X				X	
158039	Apr-00	9	X				X	
159909	Jun-00	6						X
161774	Jul-00	9	X				X	
161882	Aug-00	1	X					

**Table 4.** EDMOM's recommended induction schedule for FY-00.

FY-01								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158816	Nov-00	5					X	
159583	Nov-00	4				X		
163530	Nov-00	9	X				X	
159911	Dec-00	7	X		X			
163033	Dec-00	20	X		X	X		
163403	Dec-00	5					X	
164401	Dec-00	5					X	
161242	Jan-01	7	X		X			
163521	Jan-01	5					X	
163529	Jan-01	5					X	
160433	Feb-01	5					X	
161116	Feb-01	5					X	
161350	Feb-01	7	X		X			
160787	Mar-01	20	X		X	X		
161779	Apr-01	1	X					

**Table 5.** EDMOM's recommended induction schedule for FY-01.

FY-02								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158032	Oct-01	4				X		
158035	Oct-01	4				X		
160432	Oct-01	4				X		
161348	Oct-01	4				X		
160791	Nov-01	5					X	
161881	Nov-01	8	X			X		
163396	Nov-01	5					X	
163892	Nov-01	1	X					
160436	Dec-01	8	X			X		
161884	Dec-01	8	X			X		
163402	Dec-01	5					X	
163400	Jan-02	21	X		X		X	
158030	Feb-02	20	X		X	X		
163031	Feb-02	20	X		X	X		
163398	Mar-02	7	X		X			
159584	Apr-02	8	X			X		
161244	Apr-02	21	X		X		X	
161349	Apr-02	20	X		X	X		
161352	May-02	21	X		X		X	
164403	May-02	1	X					
161115	Jun-02	21	X		X		X	
161243	Jun-02	21	X		X		X	

**Table 6.** EDMOM's recommended induction schedule for FY-02.

FY-03								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158804	Oct-02	8	X			X		
161885	Oct-02	20	X		X	X		
162224	Oct-02	20	X		X	X		
163045	Oct-02	20	X		X	X		
162228	Nov-02	32	X		X	X		X
163032	Nov-02	32	X		X	X		X
162936	Dec-02	32	X		X	X		X
161882	Jan-03	30			X	X		X
158802	Feb-03	8	X			X		
161245	Mar-03	20	X		X	X		
161116	Apr-03	22	X		X			X
158029	May-03	10	X					X
163048	May-03	20	X		X	X		
161779	Jul-03	30			X	X		X
160786	Aug-03	8	X			X		
161347	Aug-03	22	X		X			X
163525	Sep-03	11		X	X			

**Table 7.** EDMOM's recommended induction schedule for FY-03.

FY-04								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
160709	Oct-03	20	X		X	X		
158801	Nov-03	10	X					X
163046	Nov-03	20	X		X	X		
163047	Nov-03	8	X			X		
160437	Dec-03	8	X			X		
162230	Jan-04	20	X		X	X		
162939	Feb-04	20	X		X	X		
162934	Mar-04	8	X			X		
163884	Mar-04	1	X					
162938	Apr-04	20	X		X	X		
163529	Apr-04	10	X					X
159585	May-04	1	X					
163891	May-04	17			X			X
158040	Jun-04	10	X					X
158805	Jul-04	10	X					X
163406	Jul-04	1	X					
163887	Jul-04	17			X			X
159583	Aug-04	10	X					X
159909	Aug-04	1	X					

**Table 8.** EDMOM's recommended induction schedule for FY-04.

FY-05								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158816	Oct-04	10	X					X
161348	Oct-04	1	X					
161883	Oct-04	7	X		X			
163034	Oct-04	1	X					
163397	Oct-04	7	X		X			
161118	Nov-04	1	X					
161119	Nov-04	7	X		X			
161774	Nov-04	17			X			X
160609	Dec-04	1	X					
158650	Jan-05	10	X					X
163399	Jan-05	7	X		X			
163395	Feb-05	7	X		X			
163404	Apr-05	1	X					
163520	Apr-05	1	X					
163524	Apr-05	11		X	X			
158034	May-05	1	X					
160432	May-05	10	X					X
163523	May-05	7	X		X			
163035	Jun-05	1	X					
161348	Jul-05	17			X			X

**Table 9.** EDMOM's recommended induction schedule for FY-05.



FY-06								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158032	Oct-05	10	X					X
160707	Oct-05	1	X					
161120	Oct-05	10	X					X
161880	Oct-05	1	X					
162227	Oct-05	1	X					
162935	Oct-05	10	X					X
163030	Oct-05	1	X					
163396	Oct-05	10	X					X
163401	Oct-05	7	X		X			
163402	Oct-05	1	X					
163403	Oct-05	1	X					
163047	Nov-05	17			X			X
163521	Nov-05	10	X					X
158649	Dec-05	10	X					X
160788	Dec-05	1	X					
158033	Jan-06	1	X					
158800	Jan-06	10	X					X
160433	Jan-06	10	X					X
164401	Jan-06	10	X					X
163884	Mar-06	3			X			
161884	Jun-06	17			X			X
163049	Jul-06	7	X		X			

**Table 10.** EDMOM's recommended induction schedule for FY-06.

FY-07								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158807	Oct-06	1	X					
159586	Oct-06	1	X					
159907	Oct-06	1	X					
159912	Oct-06	2		X				
160434	Oct-06	10	X					X
160791	Oct-06	14		X				X
161775	Oct-06	11		X	X			
163034	Oct-06	3			X			
163522	Oct-06	11		X	X			
163886	Oct-06	11		X	X			
164402	Oct-06	1	X					
158035	Nov-06	14		X				X
161118	Nov-06	3			X			
158810	Dec-06	14		X				X
158811	Dec-06	14		X				X
159587	Dec-06	14		X				X
159908	Dec-06	14		X				X
160706	Jan-07	14		X				X
163527	Jan-07	27		X	X			X
158544	Feb-07	14		X				X
158815	Feb-07	14		X				X
158540	Mar-07	14		X				X
158804	Mar-07	6						X
163404	Apr-07	3			X			
163520	Apr-07	3			X			
159585	Aug-07	3			X			
160609	Sep-07	3			X			

**Table 11.** EDMOM's recommended induction schedule for FY-07.

FY-08								
Aircraft	Period	Option	SDLMI	SDLMI2	WCS	8989A	89A	ICAPIII
163526	Oct-07	2		X				
163528	Oct-07	11		X	X			
163887	Oct-07	2		X				
163889	Oct-07	2		X				
163890	Oct-07	11		X	X			
163891	Oct-07	2		X				
163526	Nov-07	17			X			X
163889	Nov-07	17			X			X
158036	Dec-07	2		X				
161881	Dec-07	17			X			X
163406	Dec-07	17			X			X
158036	Jan-08	3			X			
161774	Jan-08	2		X				
162934	Jan-08	17			X			X
163888	Jan-08	14		X				X
156481	Feb-08	11		X	X			
161882	Feb-08	2		X				
158039	Mar-08	14		X				X
163530	Apr-08	27		X	X			X
163402	May-08	17			X			X

**Table 12.** EDMOM's recommended induction schedule for FY-08.

FY-09								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
161779	Oct-08	2		X				
164402	Oct-08	17			X			X
160786	Nov-08	6						X
163403	Nov-08	17			X			X
158802	Dec-08	6						X
161245	Dec-08	6						X
160787	Jan-09	6						X
161349	Jan-09	6						X
160709	Feb-09	6						X
161244	Feb-09	6						X
158030	Mar-09	6						X
161243	Mar-09	6						X

**Table 13.** EDMOM's recommended induction schedule for FY-09.

**THIS PAGE INTENTIONALLY LEFT BLANK**

## APPENDIX C. MODEL FLEXIBILITY INDUCTION SCHEDULE

Tables 14 to 24 depict EDMOM's recommended induction schedule for each EA-6B through FY-09 if aircraft utilization rate was doubled for a six-month period. Included are the recommended induction period, option and services included in the option.

FY-99								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158035	FY-99	1	X					
158540	FY-99	20	X		X	X		
158544	FY-99	20	X		X	X		
158810	FY-99	20	X		X	X		
158811	FY-99	20	X		X	X		
158815	FY-99	20	X		X	X		
159587	FY-99	20	X		X	X		
159908	FY-99	20	X		X	X		
159912	FY-99	1	X					
160706	FY-99	20	X		X	X		
160791	FY-99	1	X					
161775	FY-99	1	X					
163522	FY-99	1	X					
163524	FY-99	1	X					
163525	FY-99	1	X					
163527	FY-99	9	X				X	
163528	FY-99	1	X					
163886	FY-99	1	X					
163890	FY-99	1	X					
163396	FY-99	3			X			

**Table 14.** EDMOM's recommended induction schedule for FY-99 if aircraft utilization rate was doubled for a six-month period. To allow a dovetailing of the Master Plan with EDMOM's recommendations, EDMOM uses the Master Plan's FY-99 induction schedule.

FY-00								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158036	Oct-99	1	X					
163526	Oct-99	1	X					
163888	Oct-99	1	X					
163891	Oct-99	1	X					
156481	Nov-99	10	X					X
159583	Nov-99	4				X		
160707	Nov-99	4				X		
161120	Nov-99	5					X	
163889	Nov-99	9	X				X	
158805	Dec-99	4				X		
160788	Dec-99	4				X		
161116	Dec-99	5					X	
163887	Dec-99	9	X				X	
158039	Jan-00	1	X					
158650	Jan-00	4				X		
158800	Jan-00	4				X		
160433	Jan-00	5					X	
163521	Jan-00	5					X	
163404	Feb-00	5					X	
158029	Mar-00	5					X	
158816	Mar-00	5					X	
161347	Apr-00	5					X	
163530	Apr-00	1	X					
164401	Apr-00	5					X	
159909	Jun-00	6						X
161774	Jul-00	9	X				X	
161882	Aug-00	1	X					

**Table 15.** EDMOM's recommended induction schedule for FY-00 if aircraft utilization rate was doubled for a six-month period.

FY-01								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158040	Nov-00	4				X		
160787	Nov-00	20	X		X	X		
163529	Nov-00	5					X	
158649	Dec-00	5					X	
163031	Dec-00	7	X		X			
161243	Feb-01	21	X		X		X	
161350	Feb-01	21	X		X		X	
160791	Apr-01	5					X	
163525	Apr-01	5					X	
161779	May-01	1	X					
163396	May-01	5					X	

**Table 16.** EDMOM's recommended induction schedule for FY-01 if aircraft utilization rate was doubled for a six-month period.



FY-02								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158030	Oct-01	20	X		X	X		
158032	Oct-01	4				X		
158035	Oct-01	4				X		
160432	Oct-01	4				X		
161881	Nov-01	8	X			X		
163892	Nov-01	9	X				X	
160436	Dec-01	8	X			X		
161884	Dec-01	8	X			X		
163400	Jan-02	21	X		X		X	
161244	Feb-02	21	X		X		X	
161885	Feb-02	20	X		X	X		
163891	Feb-02	5					X	
163045	Mar-02	20	X		X	X		
159584	Apr-02	8	X			X		
161242	Apr-02	21	X		X		X	
161352	Apr-02	21	X		X		X	
159911	May-02	21	X		X		X	
164403	May-02	9	X				X	
161119	Jun-02	21	X		X		X	

**Table 17.** EDMOM's recommended induction schedule for FY-02 if aircraft utilization rate was doubled for a six-month period.

FY-03								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158804	Oct-02	8	X			X		
161245	Oct-02	20	X		X	X		
161349	Oct-02	20	X		X	X		
162224	Oct-02	20	X		X	X		
162228	Oct-02	20	X		X	X		
163033	Oct-02	20	X		X	X		
162939	Nov-02	32	X		X	X		X
163048	Nov-02	20	X		X	X		
161882	Jan-03	30			X	X		X
158802	Feb-03	8	X			X		
161779	Feb-03	30			X	X		X
161347	Apr-03	22	X		X			X
158029	May-03	10	X					X
161116	May-03	22	X		X			X
162230	Jul-03	20	X		X	X		
160786	Aug-03	8	X			X		
162938	Aug-03	32	X		X	X		X
163525	Sep-03	27		X	X			X

**Table 18.** EDMOM's recommended induction schedule for FY-03 if aircraft utilization rate was doubled for a six-month period.

FY-04								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
163032	Oct-03	20	X		X	X		
158801	Nov-03	8	X			X		
163046	Nov-03	32	X		X	X		X
163047	Nov-03	8	X			X		
160437	Dec-03	8	X			X		
162936	Jan-04	20	X		X	X		
160709	Feb-04	20	X		X	X		
162934	Mar-04	8	X			X		
163884	Mar-04	1	X					
161883	Apr-04	20	X		X	X		
163529	Apr-04	10	X					X
159585	May-04	1	X					
163397	May-04	7	X		X			
163399	Jul-04	7	X		X			
163406	Jul-04	1	X					
163524	Aug-04	11		X	X			

**Table 19.** EDMOM's recommended induction schedule for FY-04 if aircraft utilization rate was doubled for a six-month period.

FY-05								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158816	Oct-04	10	X					X
159909	Oct-04	1	X					
163887	Oct-04	17			X			X
158040	Nov-04	10	X					X
161118	Nov-04	1	X					
163523	Nov-04	7	X		X			
158805	Dec-04	10	X					X
160609	Dec-04	1	X					
158650	Jan-05	10	X					X
159583	Jan-05	10	X					X
163034	Jan-05	7	X		X			
161348	Feb-05	7	X		X			
161774	Apr-05	17			X			X
158034	May-05	1	X					
160432	May-05	10	X					X
163395	May-05	7	X		X			
163035	Jun-05	1	X					
163396	Jul-05	10	X					X
163402	Jul-05	1	X					
162935	Aug-05	1	X					
160707	Sep-05	10	X					X
163404	Sep-05	22	X		X			X

**Table 20.** EDMOM's recommended induction schedule for FY-05 if aircraft utilization rate was doubled for a six-month period.

FY-06								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158032	Oct-05	10	X					X
161115	Oct-05	7	X		X			
161120	Oct-05	10	X					X
161880	Oct-05	1	X					
162227	Oct-05	1	X					
163030	Oct-05	1	X					
163398	Oct-05	7	X		X			
163401	Oct-05	7	X		X			
163403	Oct-05	1	X					
163521	Oct-05	10	X					X
163520	Nov-05	7	X		X			
163891	Nov-05	17			X			X
158649	Dec-05	10	X					X
160788	Dec-05	10	X					X
158033	Jan-06	1	X					
158800	Jan-06	10	X					X
160433	Jan-06	10	X					X
163049	Jan-06	7	X		X			
164401	Jan-06	10	X					X
161243	Feb-06	6						X
161884	Feb-06	17			X			X
163884	Apr-06	3			X			

**Table 21.** EDMOM's recommended induction schedule for FY-06 if aircraft utilization rate was doubled for a six-month period.

FY-07								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158807	Oct-06	1	X					
159586	Oct-06	1	X					
159907	Oct-06	1	X					
159912	Oct-06	2		X				
160434	Oct-06	10	X					X
160791	Oct-06	14		X				X
161775	Oct-06	11		X	X			
163522	Oct-06	11		X	X			
163886	Oct-06	11		X	X			
164402	Oct-06	1	X					
158035	Nov-06	14		X				X
161118	Nov-06	3			X			
163527	Nov-06	27		X	X			X
159587	Dec-06	14		X				X
159908	Dec-06	14		X				X
158540	Jan-07	14		X				X
158544	Jan-07	14		X				X
158815	Feb-07	14		X				X
159585	Feb-07	3			X			
160706	Feb-07	14		X				X
158810	Mar-07	14		X				X
158811	Mar-07	14		X				X
160609	Mar-07	3			X			

**Table 22.** EDMOM's recommended induction schedule for FY-07 if aircraft utilization rate was doubled for a six-month period.

FY-08								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
158036	Oct-07	11		X	X			
158039	Oct-07	2		X				
163403	Oct-07	3			X			
163526	Oct-07	11		X	X			
163528	Oct-07	11		X	X			
163530	Oct-07	11		X	X			
163887	Oct-07	2		X				
163888	Oct-07	2		X				
163890	Oct-07	11		X	X			
163891	Oct-07	2		X				
160787	Nov-07	6						X
163889	Nov-07	27		X	X			X
158802	Dec-07	6						X
160437	Dec-07	6						X
161774	Jan-08	2		X				
162934	Jan-08	17			X			X
163406	Jan-08	17			X			X
156481	Feb-08	11		X	X			
160786	Feb-08	6						X
161242	Feb-08	6						X
161882	Feb-08	2		X				
160709	Mar-08	6						X
163402	Apr-08	3			X			
161881	May-08	17			X			X

**Table 23.** EDMOM's recommended induction schedule for FY-08 if aircraft utilization rate was doubled for a six-month period.

FY-09								
Aircraft	Period	Option	SDLM1	SDLM2	WCS	8989A	89A	ICAPIII
164402	Oct-08	3			X			
159911	Nov-08	6						X
161779	Nov-08	2		X				
163047	Nov-08	17			X			X
159584	Dec-08	6						X
161119	Dec-08	6						X
158801	Jan-09	6						X
158804	Jan-09	6						X
160436	Feb-09	6						X
163892	Feb-09	6						X
158030	Mar-09	6						X
164403	Mar-09	6						X

**Table 24.** EDMOM's recommended induction schedule for FY-09 if aircraft utilization rate was doubled for a six-month period.



THIS PAGE INTENTIONALLY LEFT BLANK.

## LIST OF REFERENCES

Albright, M.H., *An Optimization-Based Decision Support Model for the Navy H-60 Helicopter Preventive Maintenance Program*, M.S. Thesis in Operations Research, Naval Postgraduate School, Monterey, CA, September 1998.

Brooke, A., Kendrick, D., Meeraus, A., and Raman, R., *GAMS: Language Guide*, GAMS Development Corporation, Washington DC, 1997.

Brown, G.G., Dell, R.F., and Wood, R.K., *Optimization and Persistence*, Interfaces, Vol. 27, No. 5 (September/October), pp. 15-37, 1997.

Commander, Electronic Combat Wing, U.S. Pacific Fleet (COMVAQWINGPAC), *EA-6B Fatigue Life Expenditure Management Program*, Instruction 3081.1, Oak Harbor, WA, 02 June 1997.

Commander, Electronic Combat Wing, U.S. Pacific Fleet (COMVAQWINGPAC), *14<sup>th</sup> EA-6B Operational Advisory Group (OAG) and Executive Steering Committee (ESC) Top Ten Warfighting Priorities*, Naval Message 091219ZOCT98, Oak Harbor, WA, 09 October 1998.

Electronic Attack Squadron One Twenty Eight, Photo courtesy LT Greg Pederson. [<http://www.naswi.navy.mil/vaq-128/vaq-128.htm>], Naval Air Station, Whidbey Island, WA, August 1999.

Ellis G., and Tierney B., Multiple phone conversations between Gary Ellis and Brian Tierney, SEMCOR Aviation Systems Division, Lexington Park, MD, and the author, January-August 1999.

ILOG, *Using the CPLEX Callable Library*, ILOG Inc., Incline Village, NV, 1997.

Jones, J.A., *Simulating an Isochronal Scheduled Inspection System for the P-3 Orion*, M.S. Thesis in Operations Research, Naval Postgraduate School, Monterey, CA, September 1998.

Naval Air Systems Command (NAVAIR), *Aircraft Service Period Adjustment*, Instruction 4730.10A, Washington, DC, 15 October 1991.

Naval Air Systems Command (NAVAIR), *Weapon System Planning Document for EA-6B Aircraft*, Notice 13100, Patuxent River, MD, 07 October 1997.

Naval Air Systems Command (NAVAIR), *Naval Air Systems Command Homepage, About Us*, [<http://www.navair.navy.mil/aboutus/aboutus.cfm>], Patuxent River, MD, December 1998a.

Naval Air Systems Command (NAVAIR), *Standard Depot Level Maintenance (SDLM) Specification: Navy Model EA-6B Aircraft*, Patuxent River, MD, 01 July 1998b.

Northrop Grumman, Photos courtesy of Don Schroeder, St. Augustine, FL, August 1999.

Office of the Chief of Naval Operations (OPNAV), *Policies and Peacetime Planning Factors Governing the Use of Naval Aircraft*, Instruction 3110.11T, Washington, DC, 19 February 1993.

Office of the Chief of Naval Operations (OPNAV), *The Naval Aviation Maintenance Program (NAMP)*, Instruction 4790.2G, Washington, DC, 01 February 1998.

Office of the Chief of Naval Operations (OPNAV), *Naval Aircraft Pipeline, Operational Loss Rate, Utilization Planning Factors*, Letter 13000: Ser N88G10, Washington, DC, 13 June 1999.

Patterson, M.D., *Optimizing the Navy's Transition to the Integrated Maintenance Concept for the H-60 Helicopter*, M.S. Thesis in Operations Research, Naval Postgraduate School, Monterey, CA, September 1997.

Wood, S A., E-mail from Shelly A. Wood, Naval Air Systems Command, Patuxent River, MD, 02 September 1999.

## INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center.....2  
8725 John J. Kingman Rd., STE 0944  
Ft. Belvoir, VA 22060-6218
  
2. Dudley Knox Library.....2  
Naval Postgraduate School  
411 Dryer Road  
Monterey, CA 93943-5101
  
3. CAPT James Powell, Code IW/PL.....1  
Asst. Provost for Military Faculty & OR/TW Chair  
Naval Postgraduate School  
Monterey, CA 93943-5002
  
4. CAPT Steve Enewald..... 1  
Program Executive Office (PMA-234)  
IPT Building  
471234 Buse Road  
Patuxent River, MD 20670-1547
  
5. CDR Tom Payne..... 1  
Program Executive Office (PMA-234)  
IPT Building  
471234 Buse Road  
Patuxent River, MD 20670-1547
  
6. CDR Barb Bell..... 1  
Program Executive Office (PMA-234)  
IPT Building  
471234 Buse Road  
Patuxent River, MD 20670-1547
  
7. Gary Ellis.....1  
SEMCOR, Aviation Systems Division  
46621 Corporation Drive  
Lexington Park, MD 20653

8. Professor Robert F. Dell, Code OR/De.....1  
Department of Operations Research  
Naval Postgraduate School  
Monterey, CA 93943-5002
9. LCDR Bradley P. Meeks.....4  
1543 SW Putnam Drive  
Oak Harbor, WA 98277